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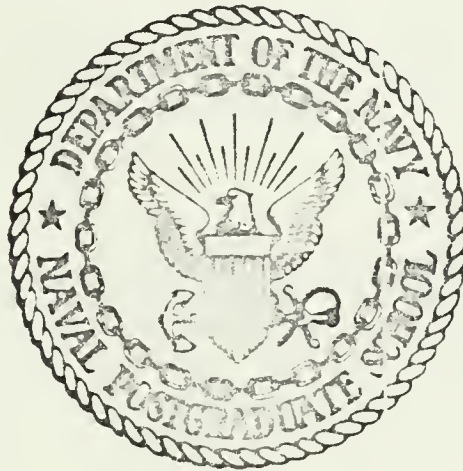
A COMPUTER SIMULATION OF ASW INTERACTIONS

by

Charles Donald Griffin



# United States Naval Postgraduate School



## THE SIS

A COMPUTER SIMULATION OF ASW INTERACTIONS

by

Charles Donald Griffin, Jr.

Thesis Advisor:

A. F. Andrus

March 1971

*Approved for public release; distribution unlimited.*

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A Computer Simulation of ASW Interactions

by

Charles Donald Griffin, Jr.  
Lieutenant Commander, United States Navy  
B.S., United States Naval Academy, 1962

Submitted in partial fulfillment of the  
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL  
March 1971



## ABSTRACT

The model presented in this thesis is a computer simulation model of ASW interactions between a formation of high value group ships, protected by some screening ships, and some penetrating submarines. The model is designed for use as an aid in improving the ability of a proposed screening tactic in the detection of a penetrating submarine. A systematic procedure to improve a screen's effectiveness against a known submarine threat is demonstrated, and an example problem is worked using this procedure.



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## I. INTRODUCTION

In the present era of a continuing and growing Sino-Soviet submarine threat, the problem of effective anti-submarine warfare (ASW) to protect a high value group of shipping is of considerable interest to the Naval Officer. In recent years a great deal of effort has been expended in an attempt to develop an optimal solution to the ASW problem; but, due primarily to the complexities of the environment and the resulting inability to quantitize parameters, no such optimal solution has been achieved. It is not the purpose of this paper to provide another solution technique for the ASW problem, but rather to provide a computer simulation model of an ASW action and to suggest one possible use for the model.

The model presented in this paper is designed for use as an aid in the design of ASW screens by providing measures of effectiveness of a screen in the detection of penetrating submarines, the number of attacks made by penetrating submarines, and the number of successful attacks made by a penetrating submarine. Using the computer simulation model, the effectiveness of a simple ASW screen against penetrating submarines is maximized within the constraint limitations provided.



## II. DESCRIPTION

The model is a computer simulation of the ASW environment, utilizing an event store procedure. The model is written in FORTRAN IV for the IBM 360/67 of the U. S. Naval Postgraduate School. A copy of the program is contained in Appendix I.

Before beginning the model description, it is desirable to define a few terms commonly used in the model.

A replication is defined as one complete ASW action. The action begins with the initial courses, speeds, and locations set by the user for the ships and submarine and proceeds until termination of the action.

A run is a collection of one or more replications, each of which has the same initial values of initial courses, speeds, and locations of ships and submarine. The variation among replications in any run are caused by the randomly generated occurrences within each replication.

A high value group is a group of one or more ships to be protected by escort ships from submarine attack.

A screen is defined as a barrier formed by a group of escort ships, distributed about the high value group, whose purpose is to protect the high value group from submarine attack. In both actuality and the model there are two general screen types, the random patrol area



screen and the fixed station screen. In the random patrol area screen, screening ships are assigned a circular patrol area with a specified radius and a center that is fixed at a relative range and bearing from the high value group. The screening ships randomly patrol this area at some speed greater than that of the high value group. In the fixed station screen, the screening ships are assigned a fixed station relative to the high value group and maintain this station throughout the replication.

CPA is defined as the closest point of approach of a submarine to a screening ship.

Detection is defined as occurring when a penetrating submarine reaches a point within the detection range of a screening ship.

A formation is defined as the group of ships that make up both the high value group and its screen. The center of a formation is referred to as ZZ and may or may not be occupied by a ship.

The model is designed to simulate an ASW environment. The scenario consists of a formation, proceeding along a predetermined track and being attacked by submarines attempting to penetrate the screen in specific places. The entire ASW action takes place sufficiently far in the first quadrant of an X-Y grid to ensure positive locations at all times in the model. The ability of the individual screen ship to detect the penetrating submarines is determined by a detection range that is uniquely determined for each screen ship in each replication. If a random patrol area screen is used, the ability



of a screen ship to detect a submarine is also influenced by the location of the screen ships within their patrol area; i.e., at the extremities of the area, the screening ship may be several thousand yards closer or farther away from a penetrating submarine than is the center of the ship's patrol area. To use the model, the user must supply certain data consisting primarily of the initial locations, courses and speeds of all ships, and some curve of detection range vs. probability of detection for the individual ship's sensors. The specific data are placed on control cards in a standard format and a new set of control cards is used in each run. The flow of simulation log is contained in Figure 1.

There are five events in the model. These are:

1. A course change by a screening ship. This event, called whenever a screening ship reaches the edge of its patrol area, generates a new course for the screen ship to continue its random patrolling.
2. A detection by a screening ship. In this event the location of the detecting screen ship, detected submarine, and ZZ are noted at the time of detection.
3. A CPA by a screening ship. At CPA, the time; CPA range; screen ship and submarine identities; and locations of screen ship, submarine, and ZZ are stored in a vector for reproduction at the end of the run.



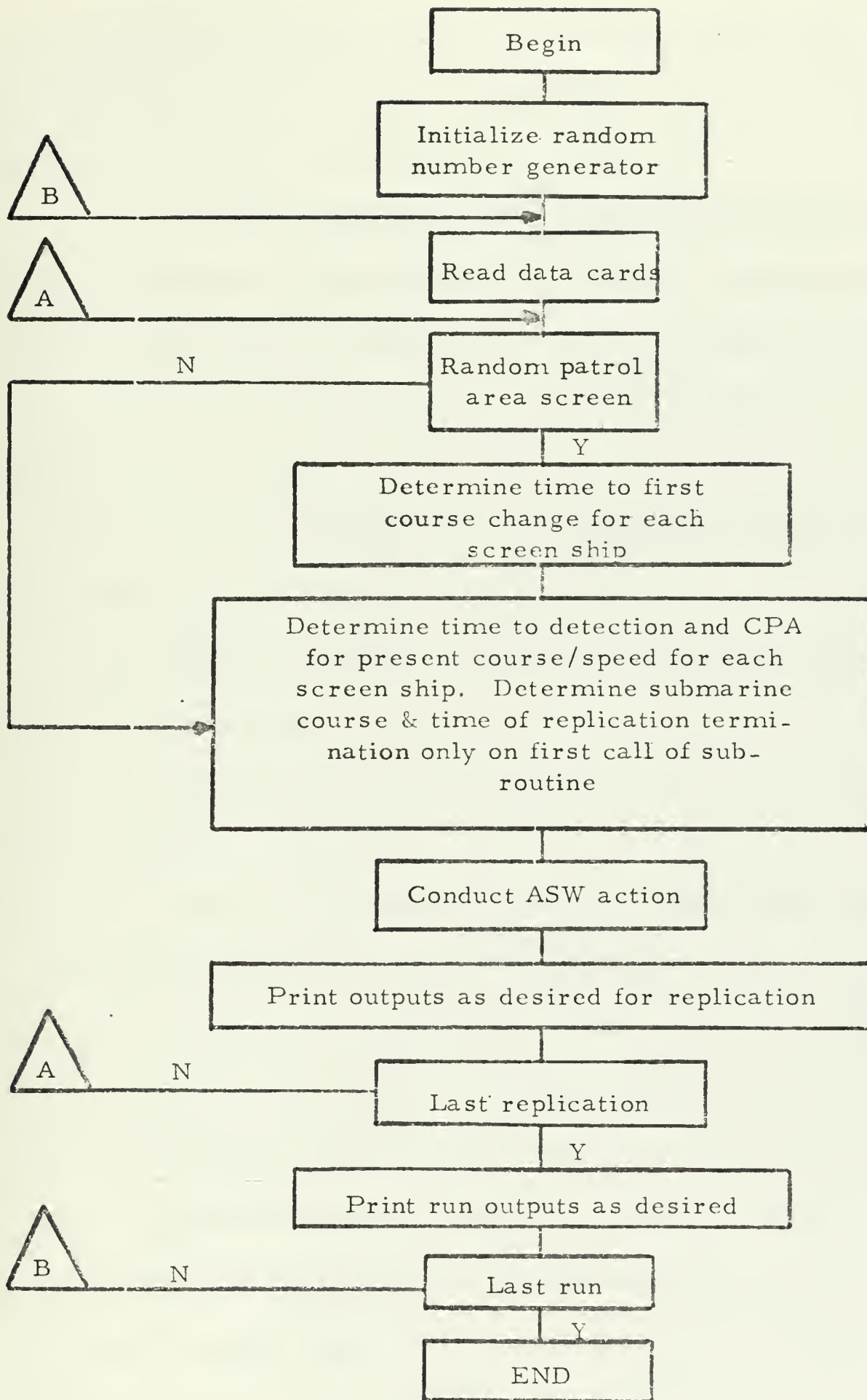


Figure 1: Simulation Logic Flow



4. An attack by the submarine on a high value group ship. The time and location of the submarine and attacked ship for each attack are noted in this event.

5. Termination of the replication. This event locates all screening ships, submarines, and high value group ships at replication termination. The mode of termination, either by successful submarine penetration or by a sufficient number of screen ship detections on the submarine, is indicated.

The measures of effectiveness for a specified formation computed in the model are:

1. The number of attacks on high value group ships made by penetrating submarines.

2. The number of times the penetrating submarines are detected by screen ships.

3. The number of successful penetrations made by the submarine.

These measures may be used to measure the effectiveness of a screen. The expression "effectiveness of the screen" refers to the probability of the screen ships detecting the penetrating submarines and, at the same time, detecting the submarine sufficiently far from ZZ to prevent attacks on the high value group ships. Clearly, a screen may be designed that will maximize the probability of detection of the penetrating submarine; but, with the necessity of minimizing the number of attacks made on high value group ships as an added constraint, the problem of designing an effective screen is complex.



With the measures of effectiveness computed in the model, the user may evaluate the relative effect of changes in parameters; e.g., changing the radius of the random patrol area on the effectiveness of the screen.

It should be noted that the model does not consider the aspect of screen ship attacks on detected submarines. There are two reasons for this. The first reason is that the inclusion of screen ship attacks on detected submarines is not considered germane to the measurement of screen effectiveness as previously defined. The second reason is that the inclusion of screen ship attacks would greatly complicate the model, adding to both time and size requirements.



### III. LIMITATIONS OF THE MODEL

The limitations of the model fall into the areas of dimension limitations and ship maneuvering limitations. A more complete description of these limitations is contained in the following paragraphs.

#### A. DIMENSION LIMITATIONS

The model is limited to certain maximum numbers of ships and replications in each run to preclude using excessive computer storage.

These limitations are:

- |                           |    |
|---------------------------|----|
| 1. Screen ships           | 10 |
| 2. Submarines             | 10 |
| 3. High value group ships | 10 |
| 4. Replications           | 20 |

#### B. MANEUVERING LIMITATIONS

1. Screening ships are constrained at all times to remain within their assigned screening stations. In the event of a detection of a submarine, the screen ships do not attack but remain in their stations.

2. Submarine maneuvering is confined to determination of a course to pass under ZZ.

3. High value group ships do not maneuver but maintain course and speed throughout the replication.



#### IV. ASSUMPTIONS

In the model certain assumptions have been made to reduce the complexity of the simulation. These assumptions are discussed in the following paragraphs with respect to screening ships, penetrating submarines, and high value group ships. These assumptions are consistent with the philosophy of model design and the measures of effectiveness derived for the model.

##### A. SCREENING SHIP ASSUMPTIONS

1. Detection ranges are assumed to be Boolean in nature; detection occurs with probability one when the penetrating submarine is within this range, and detection does not occur otherwise. The detection ranges are generated uniquely for each ship in each replication. Detection ranges are generated at the beginning of each replication using the following procedure: The model user provides some curve of detection probability vs. detection range for each sensor that is associated with the screen ships. A number is randomly drawn from a uniform distribution on  $[0, 1]$ ; this number is the detection probability for the ship in that replication. The range corresponding to this detection probability for the sensor is the detection range of the ship for that replication.

2. As indicated above, the model is designed making an assumption of a uniform distribution on  $[0, 1]$  for detection probability. If the user



feels that detection probabilities are distributed according to some distribution other than uniform, the model subroutine generating screen ship detection ranges must be rewritten by the user to reflect this different distribution.

3. Screening ships remain within their assigned stations at all times in the model.

4. Screen ships maintain a constant speed throughout each run.

5. Upon detection of a penetrating submarine, the detecting ship does not attack the submarine. The detection of the submarine is noted, and the replication continues.

6. Once a screening ship has gained contact on a penetrating submarine, the interactions of that screen ship and that submarine are terminated; i. e., as the replication continues, the screen ship does not redetect the submarine or calculate a new CPA for the submarine with each new random course change of the screen ship in its patrol area.

## B. SUBMARINE ASSUMPTIONS

1. The penetrating submarine conducts no evasive maneuvering in the model. This assumption corresponds to actual submarine maneuvering practices. The submarine fire control solution for a penetration yields a course to pass under ZZ.. Elaborate submarine maneuvering in a screen penetration is avoided, if possible, as any maneuvering has a detrimental effect on the submarine fire control solution.



2. The penetrating submarine conducts no evasive maneuvering while penetrating the screen, nor does it attack screen ships. The submarine does conduct attacks on high value group ships when arriving within a weapon's release range set by the user for each run. These attacks allow records of the effects of submarine penetrations to be maintained.

#### C. HIGH VALUE GROUP ASSUMPTIONS

1. The high value group ships do not maneuver in the model but maintain the initial course and speeds assigned by the user for each run.

2. High value group ship number 1 is always located at ZZ. If the formation for the high value group does not have a ship at ZZ, high value group ship number 1 is a dummy at ZZ, and the maximum high value group size is reduced to nine.



## V. INPUTS

Inputs to the model are by control cards, one set for each run.

The entries on the control cards are all right adjusted; i. e., the entry values set as far to the right as possible in the column width specified.

The input cards are ordered sequentially as listed below and follow the source deck directly.

### A. CARD NUMBER 1

The entry values of control card 1 are integer values.

<u>Columns</u>	<u>Definition</u>	<u>Range</u>
1 - 4	Number of screen ships in run	$1 \leq N \leq 10$
5 - 8	Number of submarines in run	$1 \leq N \leq 10$
9 - 12	Number of high value group ships in run	$1 \leq N \leq 10$
13-16	Number of replications in run	$1 \leq N \leq 20$
17-20	Number of detections of submarine by screen ships to terminate replication	$1 \leq N \leq 11$
21-24	Print screen ship detection range for each replication & average detection range for each ship for the run	0, No; 1, Yes
25-28	Print out CPA & locations of each ship & submarine in replication	0, No; 1, Yes
29-32	Print out locations of screen ship, submarine, & ZZ at time of a penetrating submarine detection by a screen ship	0, No; 1, Yes



<u>Columns</u>	<u>Definition</u>	<u>Range</u>
33-36	Minimum submarine penetration speed	$0 \leq N$
37-40	Print out locations of screen ships, submarines, & ZZ at termination of each replication	0, No; 1, Yes
41-44	Print out event calendar for each replication	0, No; 1, Yes
45-48	Print out screening ship information for each replication	0, No; 1, Yes
49-52	Print out high value group ship information for each replication	0, No; 1, Yes
53-56	Print out submarine information for each replication	0, No; 1, Yes
57-60	Submarine weapon release range (100's of yards)	
61-64	Print out locations of high value group ship & submarine at weapon release for each replication	0, No; 1, Yes

#### B. CARDS FOR SCREEN SHIPS

Cards for screen ships follow sequentially the first control card. These entries and those of following cards must be non-negative and may be integer or floating point. For each screen ship, there is one card with the following format:



<u>Columns</u>	<u>Definition</u>
1 - 8	Screen ship number
9 -16	Initial course (in radians)
17-24	Ship speed
25-32	Initial X-position
33-40	Initial Y-position
41-48	Sensor type
57-64	Patrol station radius
65-72	Initial X-position of center of random patrol area
73-80	Initial Y-position of center of random patrol area

#### C. CARDS FOR PENETRATING SUBMARINES

Cards for penetrating submarines follow directly after the cards for the screen ships. For each submarine, there is one card with the following format:

<u>Columns</u>	<u>Definition</u>
1 - 8	Submarine number
17-24	Speed ( $\geq$ minimum penetration speed)
25-32	Initial X-position
33-40	Initial Y-position

#### D. CARDS FOR HIGH VALUE GROUP SHIPS

Cards for the high value group ships follow directly after the cards for the penetrating submarines. For each high value group ship, there is one card with the following format:



<u>Columns</u>	<u>Definition</u>
1 - 8	High value group ship number
9 -16	Course
17-24	Speed
25-32	Initial X-position
33-40	Initial Y-position



## VI. OUTPUTS

The outputs of the model are of two types, general statistical outputs and specific format outputs. The general statistical outputs are always provided by the model, while the specific format outputs are provided to the user only if they are desired. To have specific format outputs, the user codes control card 1 in the appropriate column with a 1 for each specific format output desired and a 0 for those specific format outputs not desired. Examples of general statistical and specific format outputs are included in Figures 2, 3, and 4.

### A. GENERAL STATISTICAL OUTPUTS

1. The number of attacks on high value group ships by submarines for each replication and the total for the run.
2. The number of detections made on the penetrating submarine by screening ships during each replication. The upper limit of this value is set on control card one for each run.
3. The number of successful penetrations to ZZ made by penetrating submarines in each replication and the total for the run.
4. Average detection range of the penetrating submarine from ZZ for each replication; average detection range and its standard deviation of the penetrating submarine from ZZ for each run.



## B. SPECIFIC FORMAT OUTPUTS

1. Individual screen ship's generated detection ranges for each replication and the average generated detection range for the run.
2. CPA of each screen ship to a submarine in each replication.
3. Locations of ZZ, screen ship making detection, and the detected submarine at time of detection in each replication.
4. Locations of ZZ, screen ships, and submarines at the termination of each replication.
5. Event calendar for each replication..
6. Screen ship information at termination of each replication.

This information consists of:

- a. Screen ship number
- b. Course (in radians)
- c. Speed
- d. Ship X-position
- e. Ship Y-position
- f. Sensor type
- g. Generated detection range
- h. Patrol station radius
- i. X-position of center of random patrol area
- j. Y-position of center of random patrol area
- k. Time of next random course change
- l. Detection status of ship (1 if ship made detection,  
0 otherwise)
- m. Time of last position update



7. High value group ship information at termination of each replication. This information consists of:

- a. High value group ship number
- b. Course (in radians)
- c. Speed
- d. X-position
- e. Y-position
- f. Time of last position update
- g. Time first submarine passes under ZZ

8. Submarine information at termination of each replication.

This information consists of:

- a. Submarine number
- b. Course (in radians)
- c. Speed
- d. X-position
- e. Y-position
- f. Time of last position update
- g. Number of times the submarine has been detected by

different screen ships. The upper limit of this value is set on control card 1 for each run.

9. Locations of submarine and target ship at weapon release in each replication.



1. Examples of General Statistical Outputs

a. Output for each replication

WEPLAUNCH	DETECTIONS	PENETRATION
1	1	1

b. Output for each run

PENETRATIONS	WEPLAUNCH	AVDET	STDDEV
8	12	6057.6	2386.65

AVERAGE RANGE OF SUBMARINE DETECTION FROM ZZ  
IN EACH REPLICATION

7765.18	8809.04	0.0	4286.71	8633.73	6465.39
---------	---------	-----	---------	---------	---------

2. Examples of Specific Format Outputs

a. Individual screen ship's generated detection ranges for each replication & the average generated detection range for the run

SHIP	AVRANGE	REP 1	REP 2	REP 3	REP 4	REP 5
1	3049.9	0.0	1097.8	0.0	3380.6	7427.6

b. CPA of each screen ship to a submarine in a replication

SHIP	SUB	TIME	CPA	SHIPXLOC	SHIPYLOC	SUB XLOC
3.0	1.0	73.	7245.	44238.	68293.	37006.
SUB YLOC ZZ X LOC ZZ Y LOC						
67857.	40000.	64319.				

c. Location of ZZ, screen ship & detected submarine at time of detection

DETECTION TIME 64 BY DD 4 ON SUBMARINE 1 AT  
X=36733.00 Y=62409.00

Figure 2: Examples of Outputs Available in the Model



- d. Locations of ZZ, screen ships, & submarines at replication termination

TIME	SCREEN SHIP	X-POSIT	Y-POSIT
86	1	42180.0	72546.0

TIME	MAIN BODY SHIP	X-POSIT	Y-POSIT
86	1	40000.0	68652.0

TIME	SUBMARINE	X-POSIT	Y-POSIT
86	1	39910.0	68724.0

- e. Event calendar for each replication

TIME	EVENT NO.	SHIP	SUB	MAIN BODY
86	9	1	1	1

- f. Screen ship information at termination of each replication

SHIP	COURSE	SPD	X-COORD	Y-COORD	SONAR
4	1.62	15.	35434.	72029.	0.

DETRANGE	PATRAD	PATX	PATY	CCTIME	DS
4691.3	1800.	35830.	71074.	90.	1.

XYTIME

86.

- g. High value group ship information at the termination of each replication

SHIP	COURSE	SPD	X-COORD	Y-COORD	XYTIME
1	0.0	10.	40000.	68652.	86.0

EVT9TIME

86.

Figure 3: Examples of Outputs Available in the Model



- h. Submarine information at the termination of each replication

SHIP	COURSE	SPD	X-COORD	Y-COORD	XYTIME
1.	1.28	7.0	39910.	68724.	86.0

TIMES DETECTED

1.

- i. Locations of submarine & target ship at weapons' release in each replication

TIME	SUB NO	SUB X	SUB Y	TARGET NO	TAR X
74	1	37230.	67927.	1	40000.

TAR Y      LAUNCH RANGE

64654.          4000.

Figure 4: Examples of Outputs Available in the Model



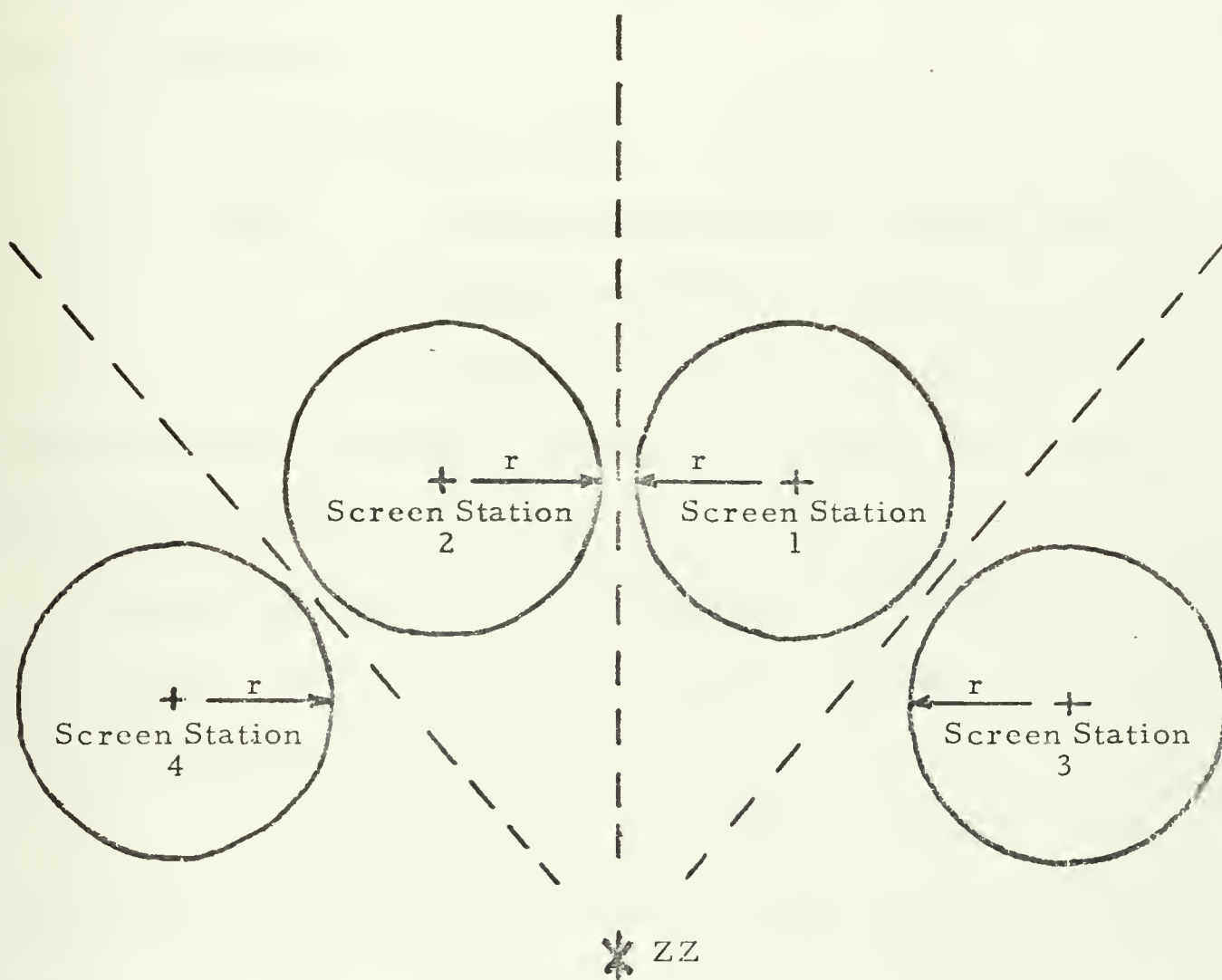
## VII. MODEL USE

As an example of the use of the ASW simulation model, the problem of detection for a screen of four ships is optimized against a penetrating submarine threat. The use of the term optimization in the context of this section refers to a search for an improved, though not necessarily optimal, solution. The screen is specified to be a random patrol area screen with the four screen ships symmetrically distributed about the formation base course in patrol areas whose centers are equally spaced. This symmetric distribution of screen ships will cover a specific arc in front of the high value group. The screen ships must be located a distance from ZZ that is at least equal to maximum submarine weapons' launch range. The submarine threat is known, with the submarine specified to pass between screen stations. The size of the main body is unspecified. (See Figure 5)

### A. PROCEDURE

The procedure used for optimization in this thesis is that of response surface methodology (RSM). This procedure focuses on the class of simulations for which a single output variable exists, and the input and output variables are quantitative and approximately continuous.





- — — — — Submarine penetration tracks
- $r$  Radius of patrol area
- $+$  Center of patrol area
- $*$  ZZ

Figure 5: Four Ship Random Patrol Area Screen with Specified Submarine Penetration Tracks



If there exists a functional relationship between the quantitative output variable and the quantitative input variables, this relationship may be expressed as:

$$y = g(x_1, \dots, x_k)$$

where:  $y$  denotes the quantitative response variable

$x_i$  denotes the  $i^{\text{th}}$  input variable

$g$  denotes the functional relationship

and the value of the response variable  $y$  lies on some  $k + 1$  dimensional response surface.

Assuming this functional relationship  $g$  to be continuous and differentiable, we will assume that a Taylor series expansion of  $g$  can be expressed as:

$$y = g(\underline{X}) = a_0 + \sum_i^k a_i X_i + \sum_i^k \sum_j^k a_{ij} X_i X_j + \dots$$

In the above notation,  $y$  is a measure of screen effectiveness determined for a screen by an average of the number of submarine detections over all replications in the runs; and  $X_i$  is the value of the  $i^{\text{th}}$  input parameter for the screen.

The problem using the simulation model is that we do not know the functional relationship  $g$ , yet we wish to maximize  $g(\underline{X})$  subject to some set constraints; i. e., maximize  $y$  subject to maximum and minimum values for  $X_i$ . The model is used to estimate the coefficients of the above Taylor series expansion by sampling. That is, the model will be used to obtain values for  $y$  for specified values of  $X_i$ ; and the technique of least squares can be used to estimate the values of the



coefficients of the Taylor series expansion. Having an approximation for the functional form of  $g(\underline{X})$ , it is possible, from this functional form, to estimate the gradient of  $g$  and to use this estimated gradient to determine the direction to move for further sampling in an effort to maximize  $g(\underline{X})$ .

If the initial samples used to determine the values of the estimators of the coefficients of the Taylor series expansion are taken from a rather restricted area, it is reasonable to make the assumption that  $g$  is linear throughout this area. That is, the functional form of  $g(\underline{X})$  may be written:

$$y = g(\underline{X}) = a_0 + \sum_{i=1}^k a_i X_i$$

and that the gradient of  $g$  is:

$$(a_1, \dots, a_k).$$

The sampling procedure is to observe at least  $k + 1$  values of  $y$  at  $k + 1$  different values of  $\underline{X}$  and to estimate the values of  $(a_0, a_1, \dots, a_k)$  by least squares. A large number of simulation runs with different values of the  $X_i$ 's may be made to determine the values of the  $a_i$ 's by least squares. By considering only the largest and smallest values of the  $X_i$ 's within the restricted area, there are  $2^k$  experiments that may be performed without redundancy to determine the value of the  $a_i$ 's.

The minimum number of experiments that will uniquely determine the values of the  $a_i$ 's in  $k + 1$  dimensional space is  $k + 1$ . Due to the high cost of computer time, the author did not consider it necessary to use



more than  $k + 1$  different values of the input variables to determine the value of the  $a_i$ 's.

To ease the computational complexity of the solution, the user may code each  $X_i$  with  $+1$  for its largest value and  $-1$  for its smallest value. By coding the input variables as  $\pm 1$ , the assumed linear function relationship  $g$  is transformed to a new linear functional relationship of the form:

$$y = b_0 + \sum_i^k b_i x_i$$

where  $x_i = \frac{X_i - \Delta^+}{\Delta^-}$

$$\Delta^+ = \frac{\text{maximum } X_i + \text{minimum } X_i}{2}$$

$$\Delta^- = \frac{\text{maximum } X_i - \text{minimum } X_i}{2}$$

and  $b_0 = a_0 + \sum_i^k a_i \Delta^+$

$$b_i = a_i \Delta^-$$

By using  $k + 1$  experiments, a unique solution for the estimated values of  $b_0$  through  $b_k$  is obtained by the simultaneous solution of  $k + 1$  linear equations.

The estimates of  $b_0$  through  $b_k$  obtained by sampling are then used as estimates of the gradient of the response surface. By using the gradient as a guide, one expects to proceed to an improved solution

$$y = b_0 + \sum_{i=1}^k b_i^2$$

where  $y$  denotes the predicted response along the path



$$(wb_1, wb_2, \dots, wb_k)$$

where  $w$  is a positive constant to indicate we are moving in the direction of increasing values of  $y$ . That is, we shall observe a new value of  $y$  at the point  $(wb_1, wb_2, \dots, wb_k)$  and hope that the observed value of  $y$  will be close to the predicted value of  $y$  using  $\hat{y}$  above. It should be noted that with increasing  $w$ , the accuracy of the predicted response may become unreliable unless the unknown functional relationship is, in fact, linear; and, thus, this path should be followed with caution. As long as observed values for  $y$  continue to increase along the path, one can continue. If the linear approximation for the unknown functional relationship has seemed satisfactory along the path, the appearance of stationary or decreasing values for  $y$  as the path is continued to be followed indicates that the linear approximation and gradient is calculated. The new path indicated by this gradient is followed until either the optimal solution is reached, or a constraint is reached; or a new linear approximation and gradient must be calculated.

## B. THE PROBLEM

For the problem being considered, the screen is specified to be a random patrol area screen with the ship located on bearing  $300^\circ$ ,  $340^\circ$ ,  $020^\circ$ , and  $060^\circ$  relative to ZZ respectively. The screen center of each patrol area is to be no greater than 10,000 yards from ZZ and no less than 4,000 yards from ZZ. The submarine is to penetrate from  $320^\circ$ ,  $000^\circ$ , and  $040^\circ$  relative to ZZ. The number of ships in the high value group is unspecified. (See Figure 5)



The model provides for each run the number of successful penetrations made by the submarine. Therefore, using the number of unsuccessful penetrations as a measure of screen effectiveness to optimize using RSM, one must first consider what variables in the model affect this measure of effectiveness. The variables that affect the output parameter of effectiveness  $y$  are: ship speed, radius of random patrol area, the range of the center of the random patrol area from ZZ, ship detection range and the location of the ship within its random patrol area. The first three variables, ship speed, radius of patrol area, and the range of the center of the patrol area from ZZ, are variables over which the user has direct control in the model. Ship detection range and the location of the ship within its random patrol area are random within the model and, therefore, not directly controlled.

For this problem, it was decided to limit the number of computer runs to eleven, with ten replications in each run, and to optimize the screen effectiveness using no more than those runs. Screen ship speed was fixed at 15 knots with the speed of the high value group at 10 knots. Thus, there are two variables to consider in optimizing the screen: radius of the patrol area ( $X_1$ ) and the range of the center of the patrol area from ZZ ( $X_2$ ).

For sampling, the initial area considered was bounded by the values of 1,000 yards and 3,000 yards for  $X_1$  and 8,000 yards and 10,000 yards for  $X_2$ . The coded variables are:



$$x_1 = \frac{X_1 - 2,000}{1,000}$$

$$x_2 = \frac{X_2 - 9,000}{1,000}$$

The initial sample points and their associated responses were:

Sample point	$X_1$	$X_2$	$x_1$	$x_2$	$y$
1	1,000	10,000	-1	1	0.533
2	1,000	8,000	-1	-1	0.567
3	3,000	8,000	-1	-1	0.667

The solution of the three simultaneous linear equations yielded the following linear approximation:

$$y = 0.457 + 0.017x_1 - 0.075x_2$$

Since the largest observed value of the response was 0.667, it was decided to choose  $w$  such that the predicted response would be in the neighborhood of 0.700. The  $w$  used was 41, which corresponded to  $y = 0.697$ . We, therefore, sampled  $y$  at the point

$$(41 (0.017), 41 (-0.075))$$

The data for the next observation was as follows:

Sample point	$w$	$X_1$	$X_2$	$x_1$	$x_2$	$y$	$\hat{y}$
4	41	2,700	5925	$w(0.017)$	$w(-0.075)$	0.667	0.697

The value of the observed response for this run was 0.667, a value less than predicted but still not less than the greatest previously observed value. It was decided to continue along this path to see if the solution would improve. Accordingly, a value for  $w$  of 49,



corresponding to a predicted response of 0.747, was chosen. We sampled  $y$  at the point

$$(49\ (0.017)\ ,\ 49\ (-0.075))..$$

The data for this next observation was as follows:

Sample point	w	$X_1$	$X_2$	$x_1$	$x_2$	y	$\hat{y}$
5	49	2800	5325	49(0.017)	49(-0.075)	0.767	0.747

By examination of the differences between predicted and response output for the previous runs, it appeared that the linear approximation was not valid. Nevertheless, as long as the response continued to increase, the path indicated by our approximation of the gradient of  $g$  appeared to indicate the direction to an improved solution. Continuing along the path, we next selected  $w = 58$ , a value corresponding to  $\hat{y} = 0.800$ , and sampled at the point

$$(58\ (0.017)\ ,\ 58\ (-0.017)).$$

The data for this next observation was as follows:

Sample point	w	$X_1$	$X_2$	$x_1$	$x_2$	y	$\hat{y}$
6	58	3000	4650	58(0.017)	58(-0.075)	0.667	0.800

As the value of the response has decreased, it was necessary to return to the point of maximum response and calculate a new linear relationship and gradient. Again, three sample points were used with the previous highest response point as one of these. These sample points and their associated responses were:



Sample point	$X_1$	$X_2$	$x_1$	$x_2$	$y$
7	1800	5325	-1	1	0.733
8	2800	5325	1	1	0.733
9	2800	4325	1	-1	0.800

The solution of the simultaneous linear equations associated with these sample points yielded the following linear approximation:

$$y = 0.7665 + 0x_1 - 0.0335x_2.$$

It is of interest to note that the value of the estimator corresponding to the value of the radius of the patrol area is zero. This indicates that the value of the radius is at its optimal value and can, therefore, no longer contribute to an improved solution. A value of  $x_1 = 0$  corresponding to  $X_1 = 2,300$  yards was, therefore, assigned in the final runs of the model.

We decided to choose  $w = 30$  such that the predicted response would be  $\hat{y} = 0.800$ . We sampled  $y$  at the point

$$(30 \ (0), \ 30 \ (-0.0335)).$$

The data for this next observation was as follows:

Sample point	$X_1$	$X_2$	$x_1$	$x_2$	$y$	$\hat{y}$
10	2300	4820	0	$30(-0.0335)$	0.800	0.800

It was realized that the predicted response of sample point 10 was not an improvement over the best previous value; but the value of  $X_2$  was approaching the overall minimum constraint of 4,000 yards, and a more cautious step was taken.



Continuing along the path for the final run, a value of  $w = 74$  corresponding to  $\hat{y} = 0.850$  was chosen. We sampled  $y$  at the point  $(74(0), 74(-0.0335))$ .

The data for this final observation was as follows:

Sample point	$X_1$	$X_2$	$x_1$	$x_2$	$y$	$\hat{y}$
11	2300	4085	0	$74(-0.0335)$	0.833	0.850

With the completion of the eleven runs of the model, the optimal screen for the given constraints was found to have values of  $X_1$  and  $X_2$  of 2,300 yards and 4,085 yards respectively. The optimal response for these values of  $X_1$  and  $X_2$  was  $y = 0.833$ ; this means that the optimized screen can be expected to detect a penetrating submarine prior to the submarine attacking the high value group 83.3% of the time. With additional runs, the response could possibly be improved; but, with only the variable  $X_2$  available to vary and with its value so close to its lower limit of 4,000 yards, the improvement would probably be marginal. A summary of the above steps is contained in Figure 6.

In this sample example, a simple screen that had several constraints was considered. By using RSM, the screen variables were optimized against the threat of submarine penetration. Using the same techniques, the model may be used to optimize more complex screens with additional variables.



Run No.	$X_1$	$X_2$	$x_1$	$x_2$	$\hat{y}$	$y$	Comments
1	1,000	10,000	-1	1	--	0.533	Value for path of steepest ascent are: (2000+17w, 9000-75w) in $x_1, x_2$ space $\hat{y}=0.457+w(0.005914)$
2	1,000	8,000	-1	-1	--	0.567	
3	3,000	8,000	1	-1	--	0.667	
4	2,700	5,925	--	--	0.697	0.667	w = 41
	2,800	5,325	--	--	0.747	0.767	w = 49 point of maximum response
6	3,000	4,650	--	--	0.80	0.667	w = 58
7	1,800	5,325	-1	1	--	0.733	
8	2,800	5,325	1	1	--	0.733	$\hat{y}=0.7665+w(0.00112225)$ b =0.0 in this solution
9	2,800	4,325	1	-1	--	0.80	
10	2,300	4,820	--	--	0.8	0.8	w = 30
11	2,300	4,085	--	--	0.85	0.833	w = 74

Figure 6: Summary of the Search for Improved Solution



## VIII. CONCLUSIONS AND RECOMMENDATIONS

The model presented in this thesis is a simulation model of ASW interactions between a formation and penetrating submarines. A procedure has been demonstrated in which the model was used to improve the effectiveness of a proposed screening tactic against a known submarine threat.

An attempt to use the model to measure the effectiveness of various screen tactics was examined. The procedure used in this attempt was to determine the average detection range of penetrating submarines from ZZ for each screen and to compare these average ranges by the analysis of variance techniques. This procedure to rank screen effectiveness in order of average detection range from ZZ, with the screen having the greatest average detection range being the most effective, had intuitive appeal. Unfortunately, the standard deviations of the average detection ranges were so great, on the order of two to three times the differences between average detection ranges of the screens, that no statistical interferences could be made with this procedure.

In an effort to use the same general procedure, an attempt was made to compare the effectiveness of proposed screen tactics by comparing the average time until first detection of a penetrating submarine. This procedure also yielded no statistically significant results for



the same reason as the previous proposal. The results of these attempts are not included in this thesis.

The model has not been successfully used to directly compare the effectiveness of various proposed screening tactics; but it may be used as shown in the preceding chapter to maximize the effectiveness of a screen, with certain constraints, against a specific submarine threat.



# APPENDIX A. COMPUTER PROGRAM

```

C      INTEGER ET, SUBKIL, DESKIL, EN, EA1, EA2, EA3, ECAL, DECAL, TEMP, KT
C      COMMON/ASWGA/ SV(10,15), DSV(10,15), SSV(10,15), DSSV(10,15), TAR(10,1
C      10), DTAR(10,10), CPA(10,10,10), ECAL(200,5), DESKIL, SUBKIL, MBKIL, PI, MA
C      2XEV, TEMP(5), SONAR(10,20), SONAR(10), R, KT, NSTAT(20), DECAL(200,5), MBK
C      3ILL, MTARK, DSTAT(20,10,10), STAT(20,2)

C      SET RANDCM NUMBER GENERATOR TO ZERO

C      CALL URN(0)

C      RESET ALL VECTORS FOR NEW RUN

C      80 CALL INIT

C      READ IN CONTROL CARD FOR NEW RUN.

C      81 READ(5,3499,END=9999)(MSTAT(I), I=1,16)
C      3499 FORMAT(16I4)
C      WRITE(6,3498)(MSTAT(I), I=1,16)
C      3498 FORMAT('0',5X,16I4,/)

C      READ IN INITIAL VALUES FOR SCREENING SHIPS, SUBMARINES AND
C      HIGH VALUE GROUP

C      L=MSTAT(1)
C      READ(5,3500)((SV(I,J), J=1,6), SV(I,8), SV(I,9), SV(I,10), I=1,L)
C      3500 FORMAT(F8.0,F8.0,F8.0,F8.0,F8.0,F8.0,F16.0,F8.0,F8.0)
C      L=MSTAT(2)
C      READ(5,3501)(SSV(I,1), (SSV(I,J), J=3,5), I=1,L)
C      3501 FORMAT(F8.0,F16.0,F8.0,F8.0)
C      L=MSTAT(3)
C      READ(5,3502)((TAR(I,J), J=1,5), I=1,L)
C      3502 FORMAT(5F8.0)

C      SET A COPY OF THE ORIGINAL DATA IN EACH VECTOR INTO ITS
C      CORRESPONDING DUMMY VECTOR. THE DUMMY VECTORS ARE USED TO HOLD
C      THE ORIGINAL COPY OF THE DATA TO RESET THE SHIP, SUBMARINE AND
C      HIGH VALUE GROUP VECTORS TO THE ORIGINAL VALUES FOR A NEW
C      REPLICATION.

C      L=MSTAT(1)
C      DO 1 I=1,L
C      DO 1 J=1,15
C      DSV(I,J)=SV(I,J)
C      1 CONTINUE
C      L=MSTAT(2)
C      DO 4 I=1,L
C      DO 4 J=1,15

```



```

DSSV(I,J)=SSV(I,J)
4 CONTINUE
N=MSTAT(3)
DO 2 K=1,N
DO 2 L=1,10
DTAR(K,L)=TAR(K,L)
2 CONTINUE

CC CC CC CC CC CC
Determine time of event 1 for each screen ship. Event 1 is the
time that an individual screen ship reaches the edge of its
random patrol area and a new course must be generated at random
that will continue the random patrol within the assigned patrol
area. Store the time for the next event 1 in the event calendar.

L=MSTAT(4)
DO 3 M=1,L
DO 82 I=1,10
IF(SV(I,1).EQ.0.0)GO TO 82
IF(SV(I,8).EQ.0.0)GO TO 82
MTIME=(SV(I,8)-1.0)/((SV(I,3)-TAR(1,3))*(2000.0/60.0))
SV(I,11)=FLOAT(MTIME)
CALL SNE(MTIME,1,1,1,0)
CONTINUE
82

CC CC CC CC CC CC
CALL SUBROUTINE TO DETERMINE TIME SUBMARINE PASSES UNDER ZZ,
COURSE OF THE SUBMARINE AND TIME SUBMARINE ARRIVES WITHIN
FIRING RANGE OF A HIGH VALUE GROUP SHIP. ENTER GENERATED EVENTS
IN EVENT CALENDAR- EVENT 9 TIME OF PASSING UNDER ZZ, EVENT 4 TIME
OF SUBMARINE ARRIVING AT FIRING POINT TO ATTACK A HIGH VALUE
GROUP SHIP.

CALL FIND(M,0,0,1)
TAKE NEXT EVENT FROM THE EVENT CALENDAR AND INDEX THE EVENT
CALENDAR

4001 CALL TNE(ET,EN,EA1,EA2,EA3,&4002)
GO TO (41,42,43,44,45,46,47,48,49),EN
41 CALL EVENT1(ET,EN,EA1,EA2,EA3,M)
GO TO 4001
42 CALL EVENT2(ET,EA1,EA2,EA3,M,&4009)
GO TO 4001
43 CALL EVENT3(ET,EA1,EA2,EA3)
GO TO 4001
44 CALL EVENT4(ET,EA1,EA2,EA3)
GO TO 4001
45 CALL EVENT5(ET,EA1,EA2,EA3)
GO TO 4001

```



```

46 CALL EVENT6(ET,EA1,EA2,EA3)
GO TO 4001
47 CALL EVENT7(ET,EA1,EA2,EA3)
GO TO 4001
48 CALL EVENT8(ET,EA1,EA2,EA3)
GO TO 4001
49 CALL EVENT9(ET,EA1,EA2,EA3)

C WRITE FOR EACH REPLICATION
C
C      WRITE(6,8002)
      FORMAT('O',4X,'WEPLAUNCH
8002      DETECTIONS
      WRITE(6,8003)DESKIL,SUBKIL,MBKIL
8003      PENETRATIONS',/)
      FORMAT('O',I9,I0X,I9,I0X,I9)
GO TO 4001

C WRITE ONLY WHEN THE SUBMARINE SUCCESSFULLY PENETRATES THE SCREEN
C AND PASSES UNDER ZZ.
C
4002 WRITE(6,4003)
4003 FORMAT('O',4X,'EVENT CALENDAR EXHAUSTED, PROBLEM COMPLETED',/)

C WRITE THE FOLLOWING ONLY IF THE USER DESIRES. THE VALUES TO BE
C PRINTED OUT ARE INDICATED ON THE CONTROL CARD BY CODING A 1 FOR
C THOSE VALUES TO BE PRINTED AND A 0 FOR THOSE VALUES NOT DESIRED.
C
4009 IF(MSTAT(11).EQ.1)CALL SNE(ET,99,EA1,EA2,EA3)
13 IF(MSTAT(12).EQ.1)GO TO 4004
14 IF(MSTAT(13).EQ.1)GO TO 4005
15 IF(MSTAT(14).EQ.1)GO TO 4006
IF(MSTAT(7).EQ.1)GO TO 4010
GO TO 12
4004 WRITE(6,4012)
NN=MSTAT(1)
WRITE(6,4007)((SV(I,J),J=1,13),I=1,NN)
GO TO 13
4005 WRITE(6,4013)
NN=MSTAT(2)
WRITE(6,4007)((SSV(I,J),J=1,7),I=1,NN)
GO TO 14
4006 WRITE(6,4014)
NN=MSTAT(3)
WRITE(6,4008)((TAR(I,J),J=1,7),I=1,NN)
GO TO 15
4010 LL=MSTAT(1)
MM=MSTAT(2)
WRITE(6,4015)
4015 FORMAT('O',4X,'SHIP SUB TIME CPA SHIPXLOC SHIPYLOC SUB

```



```

1XLOC SUB YLOC ZZ X LOC ZZ Y LOC',//)
WRITE(6,4011)((CPA(I,J,K),K=1,10),J=1,MM),I=1,LL)
GO TO 12
12 CALL REPLIC
13 CONTINUE
IF(MSTAT(6).EQ.1)CALL SONDAT
CALL FIGURE
GO TO 80
9999 STOP
4007 FORMAT('0',5X,F3.0,2X,F7.3,2X,F3.0,2X,F7.0,2X,F4.0,2X,F8.1
1,2X,F5.0,2X,F7.0,2X,F7.0,2X,F4.0,2X,F3.0,2X,F4.0,2X,/)
4008 FORMAT('0',5X,F3.0,2X,F7.3,2X,F3.0,2X,F7.0,2X,F4.0,2X,F8.1
1,2X,F5.0,2X,F7.0,2X,F7.0,2X,/)
4011 FORMAT('0',4X,F4.1,1X,F4.1,2X,F8.0,2X,F8.0,2X,F8.0
1,2X,F8.0,2X,F8.0,2X,F8.0,2X,/)
4012 FORMAT('0',4X,'SHIP COURSE SPD X-COORD Y-COORD SONAR DETRANG
1E PATRAD PATX PATY CTIME DS XYTIME',/)
4013 FORMAT('0',4X,'SHIP COURSE SPD X-COORD Y-COORD XYTIME TIMES D
1E DETECTED',/)
4014 FORMAT('0',4X,'SHIP COURSE SPD X-COORD Y-COORD XYTIME EVT9TIM
1E',/)
END

```

```

SUBROUTINE INIT
INTEGER ET,SUBKIL,DESKIL,EN,EAL,EA2,EA3,ECAL,DECAL,TEMP,KT
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),DSSV(10,15),TAR(10,1
10),DTAR(10,10),CPA(10,10),ECAL(200,5),DESKIL,SUBKIL,PI,MA
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)

```

SET ALL VECTORS AND VARIABLES FOR A NEW RUN.

```

C
C
C
PI=3.14159
DO 1 I=1,10
DO 1 J=1,15
SV(I,J)=0.0
SSV(I,J)=0.0
DSV(I,J)=0.0
DSSV(I,J)=0.0
1 CONTINUE
DO 2 L=1,10
DO 2 K=1,10
TAR(L,K)=0.0
DTAR(L,K)=0.0
SONAR(L,K)=0.0
2 CONTINUE
DO 3 M=1,200

```



```

DO 3 N=2,5
ECAL(M,1)=9999999999
DECAL(M,1)=9999999999
ECAL(M,N)=0
DECAL(M,N)=0
3 CONTINUE
DESKIL=0
SUBKIL=0
MBKIL=0
KT=0
MAXEV=200
DO 4 I=1,5
TEMP(I)=0
4 CONTINUE
DO 5 I=1,10
SONAV(I)=0.0
5 CONTINUE
DO 6 I=1,20
MSTAT(I)=0
6 CONTINUE
DO 7 I=1,10
DO 7 J=1,10
DO 7 K=1,10
CPA(I,J,K)=99999.99
7 CONTINUE
MBKILL=0
MTARK=0
DO 8 I=1,20
DO 8 J=1,10
DO 8 K=1,10
DSTAT(I,J,K)=0.0
8 CONTINUE
DO 9 I=1,20
DO 9 J=1,2
STAT(I,J)=0.0
9 CONTINUE
R=1.0
RETURN
END

```

```

SUBROUTINE FIND(M,ET,EAL,EA1,EA2,EA3)
INTEGER ET,SUBKIL,DESKIL,EN,EA1,EA2,EA3,ECAL,DECAL,TEMP,KT
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),DSSV(10,15),TAR(10,1
10),DTAR(10,10),CPA(10,10,10),ECAL(200,5),DESKIL,SUBKIL,MBKIL,PI,MA
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)

```



```

C C C C C C C C C C
R IS USED AS AN INDEX FOR EACH REPLICATION. ON THE FIRST CALL OF
THIS SUBROUTINE THE SUBMARINE COURSE AND TIME TO ZZ IS
CALCULATED.
THIS SECTION ALSO CALCULATES THE TIME OF SUBMARINE ATTACKS ON
HIGH VALUE GROUP SHIPS.
ON THE FIRST CALL OF THIS SUBROUTINE, UNIQUE DETECTION RANGES ARE
GENERATED FOR EACH SCREEN SHIP.

```

```

IF(R.GT.1.0)GO TO 10
N=MSTAT(2)
DO 1003 J=1,N
IF(SSV(J,3).LT.FLOAT(MSTAT(9)))SSV(J,3)=FLOAT(MSTAT(9))
DX=(TAR(1,4)-SSV(J,4))
DY=(TAR(1,5)-SSV(J,5))
IF(DX.LT.0.0.AND.DY.LT.0.0)GO TO 2
IF(DX.GE.0.0.AND.DY.LT.0.0)GO TO 3
IF(DX.GE.0.0.AND.DY.GE.0.0)GO TO 4
IF(DX.LT.0.0.AND.DY.GE.0.0)GO TO 5
2 RANG=SQRT((DX**2)+(DY**2))
IF(DY.EQ.0.0)GO TO 1004
ALPH=ATAN(ABS(DX/DY))
PSI=((TAR(1,3)/SSV(J,3))*SIN(ALPH))
22 IF(PSI.GT.1.0)GO TO 23
GAMMA=ARSIN(PSI)
SSV(J,2)=(PI+(ALPH+GAMMA))

```

```

C C C
CALCULATE TIME OF REPLICATION TERMINATION
1 LTIME=(RANG/(((SSV(J,3)*ABS(COS(GAMMA)))+ABS(TAR(1,3)*ABS(COS(ALPH
1)))))*(2000.0/60.0))
CALL SNE(LTIME,9,1,J,1)
IF(J.NE.1)GO TO 601
TAR(1,7)=(FLOAT(LTIME))
602 LTIM6=((RANG-FLOAT(100*MSTAT(15)))/(((SSV(J,3)*ABS(COS(GAMMA)))+AB
1S(TAR(1,3)*ABS(COS(ALPH)))))*(2000.0/60.0))
CALL SNE(LTIM6,4,EAI,J,1)
GO TO 1008
3 RANG=SQRT((DX**2)+(DY**2))
ALPH=ATAN(ABS(DX/DY))
20 PSI=((TAR(1,3)/SSV(J,3))*SIN(ALPH))
IF(PSI.GT.1.0)GO TO 21
GAMMA=ARSIN(PSI)
SSV(J,2)=(PI-(ALPH+GAMMA))
CALCULATE TIME OF REPLICATION TERMINATION
1 LTIME=(RANG/(((SSV(J,3)*ABS(COS(GAMMA)))+ABS(TAR(1,3)*ABS(COS(ALPH
1)))))*(2000.0/60.0))

```



```

CALL SNE(LTIME,9,1,J,1)
IF(J.NE.1)GO TO 603
TAR(1,7)=(FLOAT(LTIME))
604 LTIM6=((RANG-FLOAT(100*MSTAT(15)))/((SSV(J,3)*ABS(COS(GAMMA)))+AB
1S(TAR(1,3)*ABS(COS(ALPH))))*(2000.0/60.0))
CALL SNE(LTIM6,4,EAL,J,1)
GO TO 1008
21 SSV(J,3)=SSV(J,3)+2.0
GO TO 20
23 SSV(J,3)=SSV(J,3)+2.0
GO TO 22
1004 ALPH=(PI/2.0)
GO TO 22
4 RANG=SQRT((DX**2)+(DY**2))
IF(FLOAT(MSTAT(9)).LT.TAR(1,3).AND.SSV(J,3).LT.TAR(1,3))SSV(J,3)=T
1AR(1,3)+2.0
IF(DY.EQ.0.0)GO TO 24
ALPH=ATAN(ABS(DX/DY))
25 THETA=(PI-ALPH)
A=(2.0*TAR(1,3)*COS(THETA))
C=(4.0*((SSV(J,3)**2)-(TAR(1,3)**2)))
B=(0.5*(A+SQRT((A**2)+C)))
SSV(J,2)=ARCCOS(((TAR(1,3)**2)+(SSV(J,3)**2)-(B**2))/(2.0*TAR(1,3)*
1(SSV(J,3))))

```

C  
C  
C

#### CALCULATE TIME OF REPLICATION TERMINATION

```

LTIME=(RANG/(B*(2000.0/60.0)))+ET
CALL SNE(LTIME,9,EAL,J,1)
IF(J.NE.1)GO TO 605
TAR(1,7)=(FLOAT(LTIME))
606 AB=(RANG-(FLOAT(100*MSTAT(15))))
IF(AB.LT.0.0)GO TO 26
LTIM6=(AB/(B*(2000.0/60.0)))+ET
CALL SNE(LTIM6,4,EAL,J,1)
GO TO 1008
24 ALPH=((3.0*PI)/2.0)
GO TO 25
5 RANG=SQRT((DX**2)+(DY**2))
IF(FLOAT(MSTAT(9)).LT.TAR(1,3).AND.SSV(J,3).LT.TAR(1,3))SSV(J,3)=T
1AR(1,3)+2.0
IF(DY.EQ.0.0)GO TO 28
ALPH=ATAN(ABS(DX/DY))
27 THETA=(PI-ALPH)
A=(2.0*TAR(1,3)*COS(THETA))
C=(4.0*((SSV(J,3)**2)-(TAR(1,3)**2)))
B=(0.5*(A+SQRT((A**2)+C)))
SSV(J,2)=((2.0*PI)-ARCCOS(((TAR(1,3)**2)+(SSV(J,3)**2)-(B**2))/(2.0

```



```

C
C
C
1*(TAR(1,3))*(SSV(J,3))))
CALCULATE TIME OF REPLICATION TERMINATION
LTIME=(RANG/(B*(2000.0/60.0)))+ET
CALL SNE(LTIME,9,EAL,J,1)
IF(J.NE.1)GO TO 607
TAR(1,7)=(FLOAT(LTIME))
608 AB=(RANG-(FLOAT(100*MSTAT(15))))
IF(AB.LT.0.0)GO TO 26
LTIM6=(AB/(B*(2000.0/60.0)))+ET
CALL SNE(LTIM6,4,EAL,J,1)
GO TO 1008
28 ALPH=(PI/2.0)
GO TO 27
26 WRITE(6,1022)
1022 FORMAT('O',10X,'WITHIN WEAPONS LAUNCH RANGE OF ZZ AT ZERO TIME',/)
GO TO 1008
601 IF(FLOAT(LTIME).LT.TAR(1,7))TAR(1,7)=FLOAT(LTIME)
GO TO 602
603 IF(FLOAT(LTIME).LT.TAR(1,7))TAR(1,7)=FLOAT(LTIME)
GO TO 604
605 IF(FLOAT(LTIME).LT.TAR(1,7))TAR(1,7)=FLOAT(LTIME)
GO TO 606
607 IF(FLOAT(LTIME).LT.TAR(1,7))TAR(1,7)=FLOAT(LTIME)
GO TO 608
1008 CONTINUE
C
C
C
CALCULATE TIME OF WEAPONS LAUNCH AGAINST THOSE MAIN BODY SHIPS
THAT ARE WITHIN WEAPONS LAUNCH RANGE OF THE SUBMARINE DURING ITS
PENETRATION.
IF(MSTAT(3).EQ.1)GO TO 1003
WRITE(6,1011)(MSTAT(I),I=1,20)
FORMAT(20I4)
1011 RDX=((TAR(1,3))*SIN(TAR(1,2)))-(SSV(J,3))*SIN(SSV(J,2)))
RDY=((TAR(1,3))*COS(TAR(1,2)))-(SSV(J,3))*COS(SSV(J,2)))
IF(RDX.GE.0.0.AND.RDY.GE.0.0)GO TO 401
IF(RDX.LT.0.0.AND.RDY.GE.0.0)GO TO 402
IF(RDX.LT.0.0.AND.RDY.LT.0.0)GO TO 403
IF(RDX.GE.0.0.AND.RDY.LT.0.0)GO TO 404
IF(RDY.EQ.0.0)GO TO 405
401 RELCSE=ATAN(RDX/RDY)
GO TO 407
405 RELCSE=(PI/2.0)
GO TO 407
402 IF(RDY.EQ.0.0)GO TO 406
RELCS=((2.0*PI)-ATAN(ABS(RDX/RDY)))

```



```

406 GO TO 407
    RELCSE=((3.0*PI)/2.0)
403 GO TO 407
    RELCSE=(PI+ATAN(ABS(RDX/RDY)))
404 GO TO 407
    RELCSE=(PI-ATAN(ABS(RDX/RDY)))
407 RELSPD=SQRT((RDX**2)+(RDY**2))
    LL=MSTAT(3)
    DO 1009 I=2,LL
      DX=(TAR(I,4))-SSV(J,4))
      DY=(TAR(I,5))-SSV(J,5))
      RANGM=SQRT((DX**2)+(DY**2))
      IF(DX.GE.0.0.AND.DY.GE.0.0)GO TO 408
      IF(DX.LT.0.0.AND.DY.GE.0.0)GO TO 409
      IF(DX.LT.0.0.AND.DY.LT.0.0)GO TO 410
      IF(DX.GE.0.0.AND.DY.LT.0.0)GO TO 411
      IF(DY.EQ.0.0)GO TO 412
    ALPH1=ATAN(DX/DY)
408 TURN1=(ALPH1+(PI/2.0))
413 TURN2=(ALPH1+((3.0*PI)/2.0))
    IF(RELCSE.GE.TURN2.OR.RELCSE.LE.TURN1)GO TO 1003
    GAMMA2=ABS((ALPH1+PI)-RELCSE)
    POINT=RANGM*SIN(GAMMA2)
    IF((FLOAT(100*MSTAT(15)))-POINT)1003,414,414
412 ALPH1=(PI/2.0)
    GO TO 413
414 AB=RANGM*COS(GAMMA2)
    BC=SQRT(((FLOAT(100*MSTAT(15)))*2)-(POINT**2))
    LTIM6=((AB-BC)/(RELSPD*(2000.0/60.0)))+ET
    CALL SNE(LTIM6,4,0,J,I)
    GO TO 1009
409 IF(DY.EQ.0.0)GO TO 415
    ALPH1=((2.0*PI)-ATAN(ABS(DX/DY)))
416 TURN1=(ALPH1-((3.0*PI)/2.0))
    TURN2=(ALPH1-(PI/2.0))
    IF(RELCSE.LE.TURN1.OR.RELCSE.GE.TURN2)GO TO 1003
    GAMMA2=ABS((ALPH1-PI)-RELCSE)
    POINT=RANGM*SIN(GAMMA2)
    IF((FLOAT(100*MSTAT(15)))-POINT)1003,417,417
415 ALPH1=((3.0*PI)/2.0)
    GO TO 416
417 AB=RANGM*COS(GAMMA2)
    BC=SQRT(((FLOAT(100*MSTAT(15)))*2)-(POINT**2))
    LTIM6=((AB-BC)/(RELSPD*(2000.0/60.0)))+ET
    CALL SNE(LTIM6,4,0,J,I)
    GO TO 1009
410 ALPH1=(PI+ATAN(ABS(DX/DY)))

```



```

TURN1=(ALPH1+(PI/2.0))
TURN2=(ALPH1-(PI/2.0))
IF(RELCSE.LE.TURN1.AND.RELCSE.GE.TURN2)GO TO 1003
GAMMA2=ABS((ALPH1-PI)-RELCSE)
POINT=RANGM*SIN(GAMMA2)
IF((FLOAT(100*MSTAT(15)))-POINT)1003,418,418
418 AB=RANGM*COS(GAMMA2)
BC=SQRT(((FLOAT(100*MSTAT(15)))*2)-((POINT**2))
LTIM6=((AB-BC)/(RELSPD*(2000.0/60.0)))+ET
CALL SNE(LTIM6,4,0,J,I)
GO TO 1009
411 ALPH1=(PI-ATAN(ABS(DX/DY)))
TURN1=(ALPH1+(PI/2.0))
TURN2=(ALPH1-(PI/2.0))
IF(RELCSE.LE.TURN1.AND.RELCSE.GE.TURN2)GO TO 1003
GAMMA2=ABS((ALPH1+PI)-RELCSE)
POINT=RANGM*SIN(GAMMA2)
IF((FLOAT(100*MSTAT(15)))-POINT)1003,419,419
419 AB=RANGM*COS(GAMMA2)
BC=SQRT(((FLOAT(100*MSTAT(15)))*2)-((POINT**2))
LTIM6=((AB-BC)/(RELSPD*(2000.0/60.0)))+ET
CALL SNE(LTIM6,4,0,J,I)
GO TO 1009
1009 CONTINUE
1003 CONTINUE

```

THIS SECTION IS REACHED ONLY IN THE FIRST CALL OF THE SUBROUTINE

```

NN=MSTAT(1)
MM=MSTAT(2)
DO 1005 K=1,NN
DO 1005 L=1,MM
IF(SV(K,1).EQ.0.0.OR.SSV(L,1).EQ.0.0)GO TO 1005
CALL SUBROUTINE TO UNIQUELY DETERMINE DETECTION RANGE FOR EACH
SCREEN SHIP

```

```

CALL DETECT(K,M)
IF(SV(K,8).EQ.0.0)SV(K,11)=TAR(1,7)

```

DETERMINE WHEN ON PRESENT COURSE AND SPEED DETECTION OR CPA WILL OCCUR.

```

DX1=SV(K,4)-SSV(L,4)
DY1=SV(K,5)-SSV(L,5)
RANGI=SQRT((DX1**2)+(DY1**2))
IF(DX1.LT.0.0.AND.DY1.LT.0.0)GO TO 6
IF(DX1.GE.0.0.AND.DY1.LT.0.0)GO TO 7

```



```

IF(DX1.GE.0.0.AND.DY1.GE.0.0)GO TO 8
IF(DX1.LT.0.0.AND.DY1.GE.0.0)GO TO 9
6 BETA=ATAN(DX1/DY1)
GO TO 43
7 BETA=((2.0*PI)-(ATAN(ABS(DX1/DY1))))
GO TO 43
8 IF(DY1.EQ.0.0)GO TO 46
BETA=(PI+ATAN(ABS(DX1/DY1)))
GO TO 43
9 IF(DY1.EQ.0.0)GO TO 47
BETA=(PI-ATAN(ABS(DX1/DY1)))
GO TO 43
46 BETA=((3.0*PI)/2.0)
GO TO 43
47 BETA=(PI/2.0)
GO TO 43
43 RDX=SV(K,3)*SIN(SV(K,2))-SSV(L,3)*SIN(SSV(L,2))
RDY=SV(K,3)*COS(SV(K,2))-SSV(L,3)*COS(SSV(L,2))
IF(RDY.EQ.0.0)GO TO 44
THETA=ATAN(ABS(RDX/RDY))
45 ANG1=BETA+(PI/2.0)
ANG2=BETA-(PI/2.0)
IF(ANG1.GE.(2.0*PI))ANG1=ANG1-(2.0*PI)
IF(ANG2.LT.0.0)ANG2=ANG2+(2.0*PI)
RELSPD=SQRT((RDX**2)+(RDY**2))
IF(RDX.GE.0.0.AND.RDY.GE.0.0)GO TO 31
IF(RDX.LT.0.0.AND.RDY.GE.0.0)GO TO 32
IF(RDX.LT.0.0.AND.RDY.LT.0.0)GO TO 33
IF(RDX.GE.0.0.AND.RDY.LT.0.0)GO TO 34
31 RELCSE=THETA
IF(BETA.GE.PI.AND.BETA.LE.((3.0*PI)/2.0))GO TO 80
IF(BETA.GT.0.0.AND.BETA.LT.(PI/2.0))GO TO 35
IF(BETA.GE.((3.0*PI)/2.0).AND.BETA.LE.(2.0*PI).AND.RELCSE.LT.ANG1)
1 GO TO 35
IF(BETA.GT.(PI/2.0).AND.BETA.LT.PI.AND.RELCSE.GT.ANG2)GO TO 35
GO TO 80
32 RELCSE=(2.0*PI)-THETA
IF(BETA.GE.(PI/2.0).AND.BETA.LE.PI)GO TO 80
IF(BETA.GT.((3.0*PI)/2.0).AND.BETA.LT.(2.0*PI))GO TO 35
IF(BETA.GT.PI.AND.BETA.LE.((3.0*PI)/2.0).AND.RELCSE.LT.ANG1)GO TO
135
IF(BETA.GE.0.0.AND.BETA.LT.(PI/2.0).AND.RELCSE.GT.ANG2)GO TO 35
GO TO 80
33 RELCSE=PI+THETA
IF(BETA.GE.0.0.AND.BETA.LE.(PI/2.0))GO TO 80
IF(BETA.GE.PI.AND.BETA.LE.((3.0*PI)/2.0))GO TO 35
IF(BETA.GT.(PI/2.0).AND.BETA.LT.PI.AND.RELCSE.LT.ANG1)GO TO 35
IF(BETA.GT.((3.0*PI)/2.0).AND.BETA.LT.0.0.AND.RELCSE.GT.ANG2)GO TO

```







```

103 IF(DX1.GE.0.0.AND.DY1.GE.0.0)GO TO 105
104 IF(DX1.LT.0.0.AND.DY1.GE.0.0)GO TO 106
105 BETA=ATAN(DX1/DY1)
106 GO TO 107
107 BETA=((2.0*PI)-(ATAN(ABS(DX1/DY1))))
108 GO TO 107
109 IF(DY1.EQ.0.0)GO TO 125
110 BETA=ATAN(DX1/DY1)
111 GO TO 107
112 BETA=((3.0*PI)/2.0)
113 GO TO 107
114 IF(DY1.EQ.0.0)GO TO 126
115 BETA=ATAN(DX1/DY1)
116 GO TO 107
117 BETA=(PI/2.0)
118 GO TO 107
119 RDX=SV(EA1,3)*SIN(SV(EA1,2))-SSV(EA2,3)*SIN(SSV(EA2,2))
120 RDY=SV(EA1,3)*COS(SV(EA1,2))-SSV(EA2,3)*COS(SSV(EA2,2))
121 IF(RDY.EQ.0.0)GO TO 108
122 GO TO 109
123 THETA=(PI/2.0)
124 GO TO 110
125 THETA=ATAN(ABS(RDX/RDY))
126 ANG1=BETA+(PI/2.0)
127 ANG2=BETA-(PI/2.0)
128 IF(ANG1.GE.(2.0*PI))ANG1=ANG1-(2.0*PI)
129 IF(ANG2.LT.0.0)ANG2=ANG2+(2.0*PI)
130 RELSPD=SQRT((RDX**2)+(RDY**2))
131 IF(RDX.GE.0.0.AND.RDY.GE.0.0)GO TO 111
132 IF(RDX.LT.0.0.AND.RDY.GE.0.0)GO TO 112
133 IF(RDX.LT.0.0.AND.RDY.LT.0.0)GO TO 113
134 IF(RDX.GE.0.0.AND.RDY.LT.0.0)GO TO 114
135 RELCSE=THETA
136 IF(BETA.GE.PI.AND.BETA.LE.(3.0*PI)/2.0)GO TO 115
137 IF(BETA.GT.0.0.AND.BETA.LT.(PI/2.0))GO TO 116
138 IF(BETA.GE.(3.0*PI)/2.0.AND.BETA.LE.(2.0*PI).AND.RELCSE.LT.ANG1)
139 GO TO 116
140 IF(BETA.GT.(PI/2.0).AND.BETA.LT.PI.AND.RELCSE.GT.ANG2)GO TO 116
141 GO TO 115
142 RELCSE=(2.0*PI)-THETA
143 IF(BETA.GE.(PI/2.0).AND.BETA.LE.PI)GO TO 115
144 IF(BETA.GE.(3.0*PI)/2.0.AND.BETA.LT.(2.0*PI))GO TO 116
145 IF(BETA.GT.PI.AND.BETA.LE.(3.0*PI)/2.0.AND.RELCSE.LT.ANG1)GO TO
146 1116
147 IF(BETA.GE.0.0.AND.BETA.LT.(PI/2.0).AND.RELCSE.GT.ANG2)GO TO 116
148 GO TO 115
149 RELCSE=PI+THETA
150 IF(BETA.GE.0.0.AND.BETA.LE.(PI/2.0))GO TO 115

```



```

IF(BETA.GE.PI.AND.BETA.LE.((3.0*PI)/2.0))GO TO 116
IF(BETA.GT.(PI/2.0).AND.BETA.LT.PI.AND.RELCSE.LT.ANG1)GO TO 116
IF(BETA.GT.PI.AND.BETA.LT.((3.0*PI)/2.0).AND.RELCSE.GT.ANG2)GO TO
1116
1116 GO TO 115
114 RELCSE=PI-THETA
IF(BETA.GE.((3.0*PI)/2.0).AND.BETA.LE.0.0)GO TO 115
IF(BETA.GE.(PI/2.0).AND.BETA.LE.PI)GO TO 116
IF(BETA.GT.0.0.AND.BETA.LT.(PI/2.0).AND.RELCSE.LT.ANG1)GO TO 116
IF(BETA.GT.PI.AND.BETA.LT.((3.0*PI)/2.0).AND.RELCSE.GT.ANG2)GO TO
1116
1116 GO TO 115
IF(BETA-RELCSE)117,118,119
117 EPSIL=(2.0*PI)+(BETA-RELCSE)
118 GO TO 120
118 EPSIL=0.0
119 GO TO 120
119 EPSIL=(BETA-RELCSE)
120 GO TO 120
CPA(EA1,EA2,9)=ABS(RANG1*SIN(EPSIL))
A=APS(RANG1*COS(EPSIL))
LTIM1=ABS(A/((2000.0/60.0)*RELSPD))+ET
IF(LTIM1.GT.IFIX(SV(EA1,11)))GO TO 302
IF(CPA(EA1,EA2,9)-SV(EA1,7))121,121,122
C=SQRT((SV(EA1,7)**2)-((CPA(EA1,EA2,9)**2)))
LTIM2=ABS((A-C)/((2000.0/60.0)*RELSPD))+ET
IF(LTIM2.LT.IFIX(SV(EA1,11)))CALL SNE(LTIM2,2,EA1,EA2,0)
IF(LTIM1.LT.IFIX(SV(EA1,11)))CALL SNE(LTIM1,3,EA1,EA2,0)
122 GO TO 123
124 CONTINUE
115 CONTINUE
123 R=R+1.0
1006 CONTINUE
RETURN
IF(MSTAT(7).EQ.0)GO TO 301
CPA(K,L,1)=FLOAT(K)
CPA(K,L,2)=FLOAT(L)
CPA(K,L,3)=SV(K,13)
CPA(K,L,4)=RANG1
CPA(K,L,5)=SV(K,4)
CPA(K,L,6)=SV(K,5)
CPA(K,L,7)=SSV(L,4)
CPA(K,L,8)=SSV(L,5)
CPA(K,L,9)=TAR(1,4)
CPA(K,L,10)=TAR(1,5)
GO TO 301
302 IF(MSTAT(7).EQ.0)GO TO 303

```



```

CPA(EA1,EA2,1)=FLOAT(EA1)
CPA(EA1,EA2,2)=FLOAT(EA2)
CPA(EA1,EA2,3)=SV(EA1,13)
CPA(EA1,EA2,4)=RANG1
CPA(EA1,EA2,5)=SV(EA1,4)
CPA(EA1,EA2,6)=SV(EA1,5)
CPA(EA1,EA2,7)=SSV(EA2,4)
CPA(EA1,EA2,8)=SSV(EA2,5)
CPA(EA1,EA2,9)=TAR(1,4)
CPA(EA1,EA2,10)=TAR(1,5)
GO TO 303
44 THETA=(PI/2.0)
GO TO 45
1010 FORMAT(10F10.4)
END

SUBROUTINE TNE(ET,EN,EA1,EA2,EA3,*)
INTEGER ET,SUBKIL,DESKIL,EN,EA1,EA2,EA3,ECAL,DECAL,TEMP,KT
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),DSSV(10,15),TAR(10,1
10),DTAR(10,10),CPA(10,10,10),ECAL(200,5),DESKIL,SUBKIL,PI,MA
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)

SUBROUTINE PROVIDES THE NEXT SEQUENTIAL EVENT FROM THE EVENT
CALENDAR.
AFTER PROVIDING THE EVENT TO THE PROGRAM, THE EVENT IS DELETED
FROM THE EVENT CALENDAR BY THE INSERTION OF A VERY HIGH TIME OF
OCCURRENCE.
EACH TIME THE SUBROUTINE IS CALLED, THE EVENT CALENDAR IS
SEQUENTIALLY ORDERED IN ORDER OF INCREASING TIME.

CALL RPLSRT(EN)
IF(ECAL(1,1).GT.200)RETURN 1
ET=ECAL(1,1)
EN=ECAL(1,2)
EA1=ECAL(1,3)
EA2=ECAL(1,4)
EA3=ECAL(1,5)
ECAL(1,1)=9999999999
RETURN
END

```

C  
C  
C  
C  
C  
C  
C  
C



```

SUBROUTINE DETECT(N,M)
INTEGER ET,SUBKIL,DESKIL,EN,EA1,EA2,EA3,ECAL,DECAL,TEMP,KT
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),DSSV(10,15),TAR(10,1
10),DIAR(10,10),CPA(10,10),ECAL(200,5),DESKIL,SUBKIL,MBKIL,PI,MA
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)

```

SUBROUTINE PROVIDES A UNIQUE DETECTION RANGE FOR EACH SCREEN SHIP AT THE BEGINNING OF EACH REPLICATION. THE CURVES USED ARE SHIPS. PROVIDED BY THE USER FOR EACH SENSOR USED BY THE SCREEN SHIP ARE THE GENERATED VALUES OF DETECTION RANGE FOR EACH SCREEN SHIP ARE STORED IN THE SONAR VECTOR FOR USE IN DETERMINING AVERAGE GENERATED DETECTION RANGE FOR EACH REPLICATION.

```

X=URN(1)
IF(X.GT.0.5)GO TO 1
IF(X.LE.0.5.AND.X.GT.0.3)GO TO 2
IF(X.LE.0.3.AND.X.GT.0.15)GO TO 3
Y=15000.0-(66666.6666*X)
SV(N,7)=Y
SONAR(N,M)=Y
RETURN

```

100

1

```

Y=0.0
SV(N,7)=0.0
SONAR(N,M)=0.0
GO TO 100

```

2

```

Y=2000.0-(10000.0*(X-0.3))
SV(N,7)=Y
SONAR(N,M)=Y
GO TO 100

```

3 Y=5000.0-(20000.0\*(X-0.15))

```

SV(N,7)=Y
SONAR(N,M)=Y
GO TO 100
END

```

```

SUBROUTINE POSIT(ET,EN,EA1,EA2,EA3,*)
INTEGER ET,SUBKIL,DESKIL,EN,EA1,EA2,EA3,ECAL,DECAL,TEMP,KT
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),DSSV(10,15),TAR(10,1
10),DIAR(10,10),CPA(10,10),ECAL(200,5),DESKIL,SUBKIL,MBKIL,PI,MA
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)

```

SUBROUTINE LOCATES SHIPS IN X/Y COORDINATES AT ANY SPECIFIC TIME.

LOCATES ZZ (HIGH VALUE GROUP SHIP 1)

CCCCC

CCCCC



```

C
TIMES=(FLOAT(ET)-TAR(1,6))
A5=TAR(1,4)
B5=TAR(1,5)
C5=((TIMES*2000.0)/60.0)*(TAR(1,3))*(SIN(TAR(1,2)))
D5=((TIMES*2000.0)/60.0)*(TAR(1,3))*(COS(TAR(1,2)))
LOCX5=(A5+C5)
LOCY5=(B5+D5)
TAR(1,4)=LOCX5
TAR(1,5)=LOCY5
TAR(1,6)=FLOAT(ET)
IF(EN.EQ.9)GO TO 1100
IF(EA1.NE.0)GO TO 10
IF(EA1.EQ.0)GO TO 1200
1100 CONTINUE
C
LOCATES ALL SCREEN SHIPS AND SCREEN SHIP PATROL AREA CENTER
C
L=MSTAT(1)
DO 1017 I=1,L
TIMEL=(FLOAT(ET)-SV(I,13))
IF(TIMEL.LT.0.0)TIMEL=0.0
A1=SV(I,4)
B1=SV(I,5)
C1=((TIMEL*2000.0)/60.0)*(SV(I,3))*(SIN(SV(I,2)))
D1=((TIMEL*2000.0)/60.0)*(SV(I,3))*(COS(SV(I,2)))
LOCX1=(A1+C1)
LOCY1=(B1+D1)
SV(I,4)=LOCX1
SV(I,5)=LOCY1
SV(I,13)=FLOAT(ET)
AA1=(SV(I,9))
BB1=(SV(I,10))
CC1=((TIMEL*2000.0)/60.0)*(TAR(1,3))*(SIN(TAR(1,2)))
DD1=((TIMEL*2000.0)/60.0)*(TAR(1,3))*(COS(TAR(1,2)))
LOCX4=(AA1+CC1)
LOCY4=(BB1+DD1)
SV(I,9)=LOCX4
SV(I,10)=LOCY4
1017 CONTINUE
IF(EN.EQ.9)GO TO 1023
IF(EA2.NE.0)GO TO 1200
1023 L=MSTAT(2)
DO 1020 J=1,L
C
LOCATES ALL SUBMARINES
C
1019 TIME2=(FLOAT(ET)-SSV(J,6))

```



```

IF(TIME2.LT.0.0)TIME2=0.0
A2=SSV(J,4)
B2=SSV(J,5)
C2=((TIME2*2000.0)/60.0)*(SSV(J,3))*(SIN(SSV(J,2)))
D2=((TIME2*2000.0)/60.0)*(SSV(J,3))*(COS(SSV(J,2)))
LOCX2=(A2+C2)
LOCY2=(B2+D2)
SSV(J,4)=LOCX2
SSV(J,5)=LOCY2
SSV(J,6)=FLOAT(ET)
CONTINUE
1020 IF(EN.EQ.9)GO TO 1024
IF(EA3.NE.0)GO TO 1400
1024 N=MSTAT(3)
IF(N.LT.2)GO TO 1021
C
C LOCATES ALL HIGH VALUE GROUP SHIPS EXCEPT HIGH VALUE GROUP SHIP 1
C WHICH HAS BEEN LOCATED EARLIER IN THE SUBROUTINE.
C
DO 1021 L=2,N
TIME3=(FLOAT(ET)-TAR(L,6))
IF(TIME3.LT.0.0)TIME3=0.0
A3=TAR(L,4)
B3=TAR(L,5)
C3=((TIME3*2000.0)/60.0)*(TAR(L,3))*(SIN(TAR(L,2)))
D3=((TIME3*2000.0)/60.0)*(TAR(L,3))*(COS(TAR(L,2)))
LOCX3=(A3+C3)
LOCY3=(B3+D3)
TAR(L,4)=LOCX3
TAR(L,5)=LOCY3
TAR(L,6)=FLOAT(ET)
CONTINUE
1021 GO TO 1400
10 CONTINUE
C
C LOCATES A SPECIFIC SCREEN SHIP AND CENTER OF ITS PATROL AREA.
C THIS SECTION OF THE SUBROUTINE IS USED WHEN A SPECIFIC SCREEN SHIP
C NUMBER IS PASSED TO THE SUBROUTINE.
C
TIME1=(FLOAT(ET)-SV(EA1,13))
A1=SV(EA1,4)
B1=SV(EA1,5)
C1=((TIME1*2000.0)/60.0)*(SV(EA1,3))*(SIN(SV(EA1,2)))
D1=((TIME1*2000.0)/60.0)*(SV(EA1,3))*(COS(SV(EA1,2)))
LOCX1=(A1+C1)
LOCY1=(B1+D1)
SV(EA1,4)=LOCX1
SV(EA1,5)=LOCY1

```



```

SV(EA1,13)=FLOAT(ET)
AA1=SV(EA1,9)
BB1=SV(EA1,10)
CC1=((TIME1*2000.0)/60.0)*(TAR(1,3))*(SIN(TAR(1,2)))
DD1=((TIME1*2000.0)/60.0)*(TAR(1,3))*(COS(TAR(1,2)))
LOCX4=(AA1+CC1)
LOCY4=(BB1+DD1)
SV(EA1,9)=LOCX4
SV(EA1,10)=LOCY4
CONTINUE
1200
C
C
C
C
C
LOCATES A SPECIFIC SUBMARINE. THIS SECTION OF THE SUBROUTINE IS
USED ONLY WHEN A SPECIFIC SUBMARINE NUMBER IS PASSED TO THE
SUBROUTINE.
IF(EA2.EQ.0)GO TO 1300
TIME2=(FLOAT(ET)-SSV(EA2,6))
A2=SSV(EA2,4)
B2=SSV(EA2,5)
C2=((TIME2*2000.0)/60.0)*(SSV(EA2,3))*(SIN(SSV(EA2,2)))
D2=((TIME2*2000.0)/60.0)*(SSV(EA2,3))*(COS(SSV(EA2,2)))
LOCX2=(A2+C2)
LOCY2=(B2+D2)
SSV(EA2,4)=LOCX2
SSV(EA2,5)=LOCY2
SSV(EA2,6)=FLOAT(ET)
CONTINUE
1300
C
C
C
C
C
LOCATES A SPECIFIC HIGH VALUE GROUP SHIP. THIS SECTION OF THE
SUBROUTINE IS USED ONLY WHEN A SPECIFIC HIGH VALUE GROUP SHIP
NUMBER IS PASSED TO THE SUBROUTINE.
IF(EA3.EQ.0)GO TO 1400
TIME3=(FLOAT(ET)-TAR(EA3,6))
A3=TAR(EA3,4)
B3=TAR(EA3,5)
C3=((TIME3*2000.0)/60.0)*(TAR(EA3,3))*(SIN(TAR(EA3,2)))
D3=((TIME3*2000.0)/60.0)*(TAR(EA3,3))*(COS(TAR(EA3,2)))
LOCX3=(A3+C3)
LOCY3=(B3+D3)
TAR(EA3,4)=LOCX3
TAR(EA3,5)=LOCY3
TAR(EA3,6)=FLOAT(ET)
CONTINUE
RETURN
END
1400

```



```

SUBROUTINE SNE(ET,EN,EA1,EA2,EA3,*)
INTEGER ET,SUBKIL,DESKIL,EN,EA1,EA2,EA3,ECAL,DECAL,TEMP,KT
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),DSSV(10,15),TAR(10,1
10),DTAR(10,10),CPA(10,10,10),ECAL(200,5),DESKIL,SUBKIL,MBKIL,PI,MA
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)

```

C  
C  
C  
C

SUBROUTINE USED TO STORE NEW EVENTS IN THE EVENT CALENDAR IN  
SEQUENTIAL ORDER OF INCREASING TIME OF OCCURRENCE

```

CALL RPLSRT(EN)
IF(EN.EQ.99)GO TO 2003
I=1
1 IF(ECAL(I,2).NE.EN)GO TO 2
IF (ECAL(I,3).EQ.EA1.AND.ECAL(I,4).EQ.EA2.AND.ECAL(I,5).EQ.EA3)GO
1 TO 3
2 IF(FCAL(I,1).GE.999999999)GO TO 3
I=I+1
IF(I.LE.MAXFEV)GO TO 1
WRITE(6,2001)
FORNAT(1,'WARNING EVENT CALANDER FILLED')
RETURN 1
3 ECAL(I,1)=ET
ECAL(I,2)=EN
ECAL(I,3)=EA1
ECAL(I,4)=EA2
FCAL(I,5)=EA3
KT=KT+1
DECAL(KT,1)=ET
DECAL(KT,2)=EN
DECAL(KT,3)=EA1
DECAL(KT,4)=EA2
DECAL(KT,5)=EA3
RETURN
2005 WRITE(6,2006)
2003 WRITE(6,4X,'EVENT CALENDER',//,5X,'TIME',5X,'EVENT NO.',5X,'SHI
2006 1P,5X,'SUB',6X,'MAIN BODY',//)
1P,5X,'SUB',6X,'MAIN BODY',//)
WRITE(6,2004)((DECAL(I,J),J=1,5),I=1,KT)
2004 1P,5X,'SUB',6X,I4,8X,I3,8X,I3,6X,I2,10X,I2)
FORMAT(10,4X,I4,8X,I3,8X,I3,6X,I2,10X,I2)
GO TO 2005
END

```

```

SUBROUTINE RPLSRT(EN)
INTEGER ET,SUBKIL,DESKIL,EN,EA1,EA2,EA3,ECAL,DECAL,TEMP,KT
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),DSSV(10,15),TAR(10,1
10),DTAR(10,10),CPA(10,10,10),ECAL(200,5),DESKIL,SUBKIL,MBKIL,PI,MA
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK

```



```

C
C
C
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)
EVENT ORDERS THE EVENT CALENDAR IN SEQUENTIAL ORDER OF INCREASING
TIME.
IF(EN.EQ.99)GO TO 200
NPASS=MAXEV-1
DO 17 I=1,NPASS
NSTOP=MAXEV-I
DO 21 J=1,NSTOP
IF(ECAL(J,1).LE.ECAL(J+1,1))GO TO 21
IF(ECAL(J,1).GT.ECAL(J+1,1))GO TO 20
IF(ECAL(J,1).EQ.ECAL(J+1,1).AND.ECAL(J+1,1).EQ.ECAL(J+2,1).AND.
1ECAL(J+2,1).EQ.99999999)GO TO 21
IF(ECAL(I,1).EQ.ECAL(I+1,1).AND.ECAL(I+1,1).EQ.99999999)GO TO 18
20 DO 22 K=1,5
TEMP(K)=ECAL(J,K)
ECAL(J,K)=ECAL(J+1,K)
ECAL(J+1,K)=TEMP(K)
22 CONTINUE
21 CONTINUE
17 CONTINUE
GO TO 18
200 NPASS=KT-1
DO 300 I=1,NPASS
NSTOP=KT-I
DO 301 J=1,NSTOP
IF(DECAL(J,1).LE.DECAL(J+1,1))GO TO 301
IF(DECAL(J,1).GT.DECAL(J+1,1))GO TO 302
302 DO 303 K=1,5
TEMP(K)=DECAL(J,K)
DECAL(J,K)=DECAL(J+1,K)
DECAL(J+1,K)=TEMP(K)
303 CONTINUE
301 CONTINUE
300 CONTINUE
GO TO 18
18 RETURN
END
SUBROUTINE EVENT1(ET,EN,EA1,EA2,EA3,EA3,M)
INTEGER ET,SUBKIL,DFSIL,EN,EA1,EA2,EA3,ECAL,DECAL,TEMP,KT
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),TAR(10,1
10),DTAR(10,10),CPA(10,10),ECAL(200,5),DESKIL,SUBKIL,MBKIL,PI,MA
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)

```







[illegible]



```

C      IF(SV(EA1,I2).LT.1.0)CALL FIND(M,ET,EA1,EA2,EA3)
C      IF(LTIME5.GT.IFIX(TAR(1,7)))GO TO 90
CC     STORE TIME OF NEXT COURSE CHANGE
CC
C      CALL SNE(LTIME5,1,EA1,EA2,EA3)
C      GO TO 90
602   B3=(Q-(XIP-PI))
C      GO TO 603
5      XIP=(XI+PI)
C      T1=(XIP-(PI/2.0))
C      T2=(XIP+(PI/2.0))
9      Q=(2.0*PI)*URN(1)
C      IF(Q.GT.T2.OR.Q.LT.T1)GO TO 40
C      GO TO 9
40     IF(Q.GF.PI)GO TO 700
C      GAMMA=(PI-Q)
C      A1=(2.0*A*COS(GAMMA))
C      RS=(0.5*(A1+SQR((A1**2)+(4.0*C))))
DESCSE=ARCOS(((A**2)-(RS**2))/(2.0*A*B))
SV(EA1,2)=DESCSE
C      GO TO 701
700    GAMMA=(Q-PI)
C      A1=(2.0*A*COS(GAMMA))
C      RS=(0.5*(A1+SQR((A1**2)+(4.0*C))))
DESCSE=((2.0*PI)- (ARCOS(((A**2)+(B**2)-(RS**2))/(2.0*A*B))))
SV(EA1,2)=DESCSE
C      GO TO 701
701    IF(Q.GT.(XIP-PI))GO TO 702
C      B3=(Q-(XIP-PI))
703    F=(SV(EA1,8)-1.0)
C      G=(2.0*SCRLOC*COS(B3))
H=((F**2)-(SCRLOC**2))
DRM=(0.5*(G+SQR((G**2)+(4.0*H))))
LTIME4=((DRM*60.0)/(RS*2000.0))
LTIME5=LTIME4+ET
SV(EA1,I1)=LTIME5

SUBROUTINE FIND IS CALLED TO GENERATE TIME OF EITHER DETECTION OR Y
CPA FOR THE SCREEN SHIP ONLY IF THE SCREEN SHIP HAS NOT PREVIOUSLY
MADE A DETECTION ON THE SUBMARINE.

IF(SV(EA1,I2).LT.1.0)CALL FIND(M,ET,EA1,EA2,EA3)
IF(LTIME5.GT.IFIX(TAR(1,7)))GO TO 90

STORE TIME OF NEXT COURSE CHANGE

```



```

CALL SNE(LTIME5,1,EA1,EA2,EA3)
GO TO 90
702 B3=((XIP-PI)-Q)
GO TO 703
6 XIP=(PI-XI)
T1=(XIP-(PI/2.0))
T2=(XIP+(PI/2.0))
10 Q=(2.0*PI)*URN(1)
IF(Q.GT.T2.OR.Q.LT.T1)GO TO 50
GO TO 10
50 IF(Q.GE.PI)GO TO 800
GAMMA=(PI-Q)
A1=(2.0*A*COS(GAMMA))
RS=(0.5*(A1+SQR((A1**2)+(4.0*C)))
DESCSE=ARCCOS(((A**2)+(B**2)-(RS**2))/(2.0*A*B))
SV(EA1,2)=DESCSE
GO TO 801
800 GAMMA=(Q-PI)
A1=(2.0*A*COS(GAMMA))
RS=(0.5*(A1+SQR((A1**2)+(4.0*C)))
DESCSE=((2.0*PI)-(ARCCOS(((A**2)+(B**2)-(RS**2))/(2.0*A*B))))
SV(EA1,2)=DESCSE
GO TO 801
801 IF(Q.LT.(XIP+PI))GO TO 802
IF(Q.GT.(XIP+PI))GO TO 803
IF(Q.LT.T1)B3=(Q+(XIP-(PI/2.0)))
GO TO 804
802 B3=(XIP+PI)-Q
GO TO 804
803 B3=(Q-(XIP+PI))
GO TO 804
804 F=(SV(EA1,8)-1.0)
G=(2.0*SCRLOC*CCS(B3))
H=((F**2)-(SCRLOC**2))
DRM=(0.5*(GRM*60.0)/(RS*2000.0))
LTIME4=((DRM*60.0)/(RS*2000.0))
LTIME5=LTIME4+ET
SV(EA1,11)=LTIME5
C SUBROUTINE FIND IS CALLED TO GENERATE TIME OF EITHER DETECTION OR
C CPA FOR THE SCREEN SHIP ONLY IF THE SCREEN SHIP HAS NOT PREVIOUSLY
C MADE A DETECTION ON THE SUBMARINE.
C
C IF(SV(EA1,12).LT.1.0)CALL FIND(M,ET,EA1,EA2,EA3)
C IF(LTIME5.GT.FIX(TAR(1,7)))GO TO 90
C STORE TIME OF NEXT COURSE CHANGE

```



```

CALL SNE(LTIME5,1,EA1,EA2,EA3)
GO TO 90
CONTINUE
RETURN
100 WRITE(6,101)EA1,SV(EA1,4),SV(EA1,5),SV(EA1,9),SV(EA1,10),ET,M
101 FORMAT('0','SHIP',I4,2X,'OUT OF PATROL AREA. LOCATION',F8.0,F8.0,2
1X,'SCREEN CENTER',F8.0,F8.0,2X,'TIME',I5,2X,'REPLICATION',I5)
GO TO 102
END

SUBROUTINE EVFNT2(ET,EA1,EA2,EA3,M,*)
INTEGER ET,SUBKIL,DESKIL,EN,EA1,EA2,EA3,ECAL,DECAL,TEMP,KT
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),DSSV(10,15),TAR(10,1
10),DTAR(10,10),CPA(10,10),ECAL(200,5),DESKIL,SUBKIL,MBKIL,PI,MA
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)

EVENT LOCATES THE SHIPS AND SUBMARINES AT DETECTION AND CALCULATES
THE DISTANCE FROM ZZ OF THE SUBMARINE AT DETECTION. THIS VALUE IS
STORED FOR USE IN DETERMINING AVERAGE DETECTION RANGE OF THE
SUBMARINE FROM ZZ IN EACH REPLICATION AND IN THE RUN.

CALL POSIT(ET,2,EA1,EA2,EA3,1350)
DX=TAR(1,4)-SSV(EA2,4)
DY=TAR(1,5)-SSV(EA2,5)
DSTAT(M,EA1,EA2)=SQRT((DX**2)+(DY**2))
IF(MSTAT(8).EQ.0)GO TO 8004
WRITE(6,8001)ET,EA1,EA2,SV(EA1,4),SV(EA1,5)
FORMAT('0',4X,'SUBROUTINE EVENT2',//,5X,'DETECTION TIME',2X,I10,2X
1,'BY DD',I4,2X,'ON SUBMARINE',I4,2X,'AT X=',F10.2,2X,'Y=',F10.2,2X
2, '//')
8004 SSV(EA2,7)=SSV(EA2,7)+1.0
SV(EA1,12)=SV(EA1,12)+1.0
SUBKIL=SUBKIL+1
IF(SSV(EA2,7).GE.FLOAT(MSTAT(5)))GO TO 8005
GO TO 8003
1350 WRITE(6,8002)
8002 FORMAT('0','TIME USED IN SUBROUTINE POSIT GREATER THAN 200.0 MIN.',
1, '//')
8003 RETURN
8005 CALL EVENT9(ET,EA1,EA2,88)
RETURN 1
END

```



```

SUBROUTINE EVENT3(ET,EA1,EA2,EA3)
INTEGER ET,SUBKIL,DESKIL,EN,EA1,EA2,EA3,ECAL,DECAL,TEMP,KT
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),DSSV(10,15),TAR(10,1
10),DTAR(10,10),CPA(10,10,10),ECAL(200,5),DESKIL,SUBKIL,MBKIL,PI,MA
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)

```

```

EVENT LOCATES SHIPS AND SUBMARINES AT CPA AND STORES THIS VALUE
IN THE CPA VECTOR WHERE IT MAY BE PRINTED OUT AT THE END OF EACH
REPLICATION IF THE CONTROL CARD IS SO CODED BY THE USER.

```

```

CALL POSIT(ET,3,EA1,EA2,EA3,1360)
IF(EA3.EQ.99)GO TO 8006
IF(MSTAT(7).EQ.0)GO TO 8004
DX1=SV(EA1,4)-SSV(EA2,4)
DY1=SV(EA1,5)-SSV(EA2,5)
RANG1=SQR((DX1**2)+(DY1**2))
IF(CPA(EA1,EA2,4).LT.RANG1)GO TO 8004
CPA(EA1,EA2,1)=FLOAT(EA1)
CPA(EA1,EA2,2)=FLOAT(EA2)
CPA(EA1,EA2,3)=FLOAT(ET)
CPA(EA1,EA2,4)=RANG1
CPA(EA1,EA2,5)=SV(EA1,4)
CPA(EA1,EA2,6)=SV(EA1,5)
CPA(EA1,EA2,7)=SSV(EA2,4)
CPA(EA1,EA2,8)=SSV(EA2,5)
CPA(EA1,EA2,9)=TAR(1,4)
CPA(EA1,EA2,10)=TAR(1,5)

```

8004  
8006

```

RETURN
NN=MSTAT(1)
NM=MSTAT(2)
DO 8007 I=1,NN
DO 8007 J=1,NN
DX1=SV(I,4)-SSV(J,4)
DY1=SV(I,5)-SSV(J,5)
RANG1=SQR((DX1**2)+(DY1**2))
IF(CPA(I,J,4).LT.RANG1)GO TO 8007
CPA(I,J,1)=FLOAT(I)
CPA(I,J,2)=FLOAT(J)
CPA(I,J,3)=FLOAT(ET)
CPA(I,J,4)=RANG1
CPA(I,J,5)=SV(I,4)
CPA(I,J,6)=SV(I,5)
CPA(I,J,7)=SSV(J,4)
CPA(I,J,8)=SSV(J,5)
CPA(I,J,9)=TAR(1,4)
CPA(I,J,10)=TAR(1,5)
CONTINUE

```

8007



GO TO 8004  
END

SUBROUTINE EVENT4(ET,EA1,EA2,EA3)  
INTEGER ET,SUBKIL,DESKIL,EN,EA1,EA2,EA3,ECAL,DECAL,TEMP,KT  
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),DSSV(10,15),TAR(10,1  
10),DTAR(10,10),CPA(10,10,10),ECAL(200,5),DESKIL,SUBKIL,MBKIL,PI,MA  
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK  
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)

EVENT LOCATES SHIPS AND SUBMARINES AT TIME OF SUBMARINE ATTACK.  
THIS EVENT WILL PRINT OUT THE LOCATIONS OF SHIPS, ZZ AND SUBMARINE  
AT TIME OF ATTACK IF DESIRED BY THE USER. TO HAVE THE EVENT PRINT  
OUT, THE USER CODES THE CONTROL CARD WITH A 1 IN COLUMN 64 OF THE  
CONTROL CARD. IF NO OUTPUT IS DESIRED, A ZERO IS CODED IN THE  
SAME COLUMN.

MTARK=MTARK+1  
DESKIL=DESKIL+1  
IF(MSTAT(16).EQ.0)GO TO 8001  
MM=(100\*MSTAT(15))  
CALL POSIT(ET,4,EA1,EA2,EA3)  
WRITE(6,8002)ET,EA2,SSV(EA2,4),SSV(EA2,5),EA3,TAR(EA3,4),TAR(EA3,5  
1),MM  
8002 FORMAT('0',4X,'TIME',2X,'SUB NO',2X,'SUB X',2X,'SUB Y',2X,'TARGET  
1NO',2X,'TAR X',2X,'TAR Y',2X,'LAUNCH RANGE',//,5X,I4,3X,I3,3X,F6.0  
2,2X,F6.0,5X,I4,3X,F6.0,2X,F6.0,5X,I5,//)  
8001 RETURN  
END

SUBROUTINE EVENT5(ET,EN,EA1,EA2,EA3)  
INTEGER ET,SUBKIL,DESKIL,EN,EA1,EA2,EA3,ECAL,DECAL,TEMP,KT  
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),DSSV(10,15),TAR(10,1  
10),DTAR(10,10),CPA(10,10,10),ECAL(200,5),DESKIL,SUBKIL,MBKIL,PI,MA  
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK  
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)  
RETURN  
END

SUBROUTINE EVENT6(ET,EN,EA1,EA2,EA3)  
INTEGER ET,SUBKIL,DESKIL,EN,EA1,EA2,EA3,ECAL,DECAL,TEMP,KT  
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),DSSV(10,15),TAR(10,1  
10),DTAR(10,10),CPA(10,10,10),ECAL(200,5),DESKIL,SUBKIL,MBKIL,PI,MA  
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK  
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)



```

RETURN
END

SUBROUTINE EVENT7(ET,EN,EAL,EA2,EA3)
INTEGER ET,SUBKIL,DESKIL,EN,EAL,EA2,EA3,ECAL,DECAL,TEMP,KT
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),DSSV(10,15),TAR(10,1
10),DTAR(10,10),CPA(10,10),ECAL(200,5),DESKIL,SUBKIL,PI,MA
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)
RETURN
END

SUBROUTINE EVENT8(ET,EN,EAL,EA2,EA3)
INTEGER ET,SUBKIL,DESKIL,EN,EAL,EA2,EA3,ECAL,DECAL,TEMP,KT
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),DSSV(10,15),TAR(10,1
10),DTAR(10,10),CPA(10,10),ECAL(200,5),DESKIL,SUBKIL,PI,MA
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)
RETURN
END

SUBROUTINE EVENT9(ET,EAL,EA2,EA3)
INTEGER ET,SUBKIL,DESKIL,EN,EAL,EA2,EA3,ECAL,DECAL,TEMP,KT
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),DSSV(10,15),TAR(10,1
10),DTAR(10,10),CPA(10,10),ECAL(200,5),DESKIL,SUBKIL,PI,MA
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)

EVENT LOCATES SHIPS AND SUBMARINES AT THE TERMINATION OF A
REPLICATION.

CALL POSIT(ET,9,EAL,EA2,EA3,1370)
IF(EA3.EQ.88)GO TO 8009
MBKILL=MBKILL+1
MBKILL=MBKILL+1
IF(MSTAT(7).EQ.1)GO TO 8005
8009 IF(EA3.EQ.88)GO TO 8006
8008 IF(MSTAT(10).EQ.0)GO TO 8003
8004 MM=MSTAT(1)
WRITE(6,8002)
8002 FORMAT(0,4X,'TIME SCREEN SHIP X-POSIT Y-POSIT',/)
8001 WRITE(6,8001)('SV(1,13),I,SV(1,4),SV(1,5),I=1,MM)
      WRITE(6,8001)('F4.0,T17,I2,T28,F7.1,T38,F7.1,/')
      NN=MSTAT(3)
      WRITE(6,8010)

```



```

8010 FORMAT('0',4X,'TIME MAIN BODY SHIP X-POSIT Y-POSIT',/)
WRITE(6,8001){TAR(I,6),I,TAR(I,4),TAR(I,5),I=1,NN)
LL=MSTAT(2)
WRITE(6,8011)
8011 FORMAT('0',4X,'TIME SUBMARINE X-POSIT Y-POSIT',/)
8003 WRITE(6,8001){SSV(I,6),I,SSV(I,4),SSV(I,5),I=1,LL)
8005 RETURN
CALL EVENT3(ET,EA1,EA2,99)
GO TO 8008
8006 WRITE(6,8007)ET,SSV(EA2,7)
8007 FORMAT('0',4X,'RUN TERMINATED AT TIME',I5,2X,'BY DETECTION BY',F6.
10,2X,'SCREEN SHIPS',/)
GO TO 8003
END

SUBROUTINE REPLIC
INTEGER ET, SUBKIL, DESKIL, EN, EA1, EA2, EA3, ECAL, DECAL, TEMP, KT
COMMON/ASWGAM/SV(10,15), DSV(10,15), SSV(10,15), DSSV(10,15), TAR(10,1
10), DTAR(10,10), CPA(10,10,10), ECAL(200,5), DESKIL, SUBKIL, MBKIL, MA
2XEV, TEMP(5), SONAR(10,20), SONAV(10), R, KT, MSTAT(20), DECAL(200,5), MBK
3ILL, MTARK, DSTAT(20,10,10), STAT(20,2)

SUBROUTINE RESETS SHIP, SUBMARINE, AND MAIN BODY VECTORS TO THE
ORIGINAL VALUES FOR USE IN THE NEXT REPLICATION OF THE RUN

L=MSTAT(1)
DO 5 I=1,L
DO 5 J=1,15
SV(I,J)=DSV(I,J)
5 CONTINUE
N=MSTAT(2)
DO 4 K=1,N
DO 4 L=1,15
SSV(K,L)=DSSV(K,L)
4 CONTINUE
N=MSTAT(3)
DO 6 L=1,N
DO 6 K=1,10
TAR(L,K)=DTAR(L,K)
6 CONTINUE

CPA VECTOR RESET FOR NEW REPLICATION

DO 3 I=1,10
DO 3 J=1,10
DO 3 K=1,10
CPA(I,J,K)=99999.99

```



```

C
C
C
3 CONTINUE
EVENT CALENDAR AND DUMMY EVENT CALENDAR RESET FOR NEW REPLICATION
DO 7 M=1,200
DO 7 N=2,5
ECAL(M,1)=9999999999
DECAL(M,1)=9999999999
ECAL(M,N)=0
DECAL(M,N)=0
7 CONTINUE
C
C
C
COUNTERS FOR SUBMARINE PENETRATIONS, SCREEN SHIP DETECTIONS AND
SUBMARINE ATTACKS ON THE MAIN BODY RESET FOR NEW REPLICATION
SUBKIL=0
DESKIL=0
MBKIL=0
KT=0
R=1.0
RETURN
END
C
C
C
SUBROUTINE SONDAT
INTEGER ET,SUBKIL,DESKIL,EN,EAL,EA2,EA3,ECAL,DECAL,TEMP,KT
COMMON/ASWGAM/SV(10,15),DSV(10,15),SSV(10,15),DSSV(10,15),TAR(10,1
10),DTAR(10,10),CPA(10,10),ECAL(200,5),DESKIL,SUBKIL,PI,MA
2XEV,TEMP(5),SONAR(10,20),SONAV(10),R,KT,MSTAT(20),DECAL(200,5),MBK
3ILL,MTARK,DSTAT(20,10,10),STAT(20,2)
C
C
C
SUBROUTINE PRINTS SONAR INFORMATION FOR EACH SCREEN SHIP AND THE
AVERAGE GENERATED RANGE FOR THE SCREEN SHIP OVER THE REPLICATIONS
IN THE RUN.
NN=MSTAT(1)
MM=MSTAT(4)
DO 1 I=1,NN
X=0.0
SONSUM=0.0
DO 2 J=1,MM
SONSUM=SONSUM+SONAR(I,J)
X=X+1.0
2 CONTINUE
SONAV(I)=(SONSUM/X)
WRITE(6,1002)
IF(MM.GT.10)GO TO 1003
WRITE(6,1001)I,SONAV(I),(SONAR(I,J),J=1,MM)

```



```

1 CONTINUE
  RETURN
1003 WRITE(6,1004)
1004 WRITE(6,1005) I, SONAV(I), (SONAR(I, J), J=1, MM)
1005 FORMAT('0', 6X, 'SHIP', REPLICATION RANGES', //)
1006 FORMAT('0', 4X, I6, 2X, 11(F8.1, 2X), //, 21X, 10(F8.1, 2X), //)
  GO TO 1
1001 FORMAT('0', 2X, I6, 2X, 11(F8.1, 2X), //)
1002 FORMAT('0', 3X, 'SHIP', AVRANGE', REP1 REP2 REP3 REP4 REP5 REP6 REP7 REP8 REP9 REP10')
1003 REP4 REP5 REP6 REP7 REP8 REP9 REP10')
  END

SUBROUTINE FIGURE
  INTEGER ET, SUBKIL, DESKIL, EN, EA1, EA2, EA3, ECAL, DECAL, TEMP, KT
  COMMON/ASWGAM/SV(10, 15), DSV(10, 15), SSV(10, 15), DSSV(10, 15), TAR(10, 1
  10), DTAR(10, 10), CPA(10, 10, 10), ECAL(200, 5), DESKIL, SUBKIL, MBKIL, MA
  2XEV, TEMP(5), SONAR(10, 20), SONAV(10), R, KT, MSTAT(20), DECAL(200, 5), MBK
  3ILL, MTRAK, DSTAT(20, 10, 10), STAT(20, 2)

SUBROUTINE PROVIDES AVERAGE RANGE OF SUBMARINE DETECTION FROM
ZZ FOR EACH REPLICATION

  II=MSTAT(4)
  JJ=MSTAT(1)
  KK=MSTAT(2)
  DSUM=0.0
  Q=0.0
  DSQR=0.0
  DO 1001 L=1, II
    DDSUM=0.0
    T=0.0
    DO 1002 M=1, JJ
      DO 1003 N=1, KK
        IF(DSTAT(L, M, N).EQ.0.0) GO TO 1003
        DDSUM=DDSUM+DSTAT(L, M, N)
        DSUM=DSUM+DSTAT(L, M, N)
        DSQR=DSQR+(DSTAT(L, M, N)**2)
      T=T+1.0
    CONTINUE
    CONTINUE
    IF(T.EQ.0.0) GO TO 1009
    AVSUM=(DDSUM/T)
    AVSQR=(AVSUM**2)
    STAT(L, 1)=AVSUM
    STAT(L, 2)=AVSQR
    Q=Q+T
    GO TO 1001
  1003
  1002

```



```

1009 AVSUM=0.0
    AVSQR=0.0
    STAT(L,1)=0.0
    STAT(L,2)=0.0
    GO TO 1001
1001 CONTINUE
    IF(Q.EQ.0.0)GO TO 1006
    DAV=(DSUM/Q)
    IF(Q.EQ.1.0)GO TO 1008
    STD=SQR((1.0/(Q-1.0))*(DSQR-(Q*(DAV**2))))
1007 WRITE(6,1004)MBKILL,MTARK,DAV,STD
1004 FORMAT(0,5X,PENETRATIONS WEPLAUNCH AVDET STDDEV',//,10X
1,15,10X,15,4X,F8.1,3X,F8.2,/)
    WRITE(6,1006)
1006 FORMAT(0,4X,AVERAGE RANGE OF SUBMARINE DETECTION FROM ZZ IN EAC
1H REPLICATION,/)
    WRITE(6,1005)((STAT(I,J),I=1,II),J=1,2)
1005 FORMAT(10F13.2)
    RETURN
1006 MBKILL=0.0
    DAV=0.0
    STD=0.0
    GO TO 1007
1008 STD=0.0
    GO TO 1007
    END

```



## APPENDIX B: LIST OF PROGRAM VARIABLES

This appendix contains the name and definition of the symbols appearing in the computer program. This list contains only those variables using storage space in the program and does not contain those used only for temporary storage.



<u>Name</u>	<u>Definition</u>
CPA(I, J, K)	CPA information for the I <sup>th</sup> ship on the J <sup>th</sup> submarine in a replication. The values in this vector are:
CPA(I, J, 1)	Screen ship number
CPA(I, J, 2)	Penetrating submarine number
CPA(I, J, 3)	Time of CPA
CPA(I, J, 4)	CPA range
CPA(I, J, 5)	Screen ship X location at CPA
CPA(I, J, 6)	Screen ship Y location at CPA
CPA(I, J, 7)	Penetrating submarine X location at CPA
CPA(I, J, 8)	Penetrating submarine Y location at CPA
CPA(I, J, 9)	X location of ZZ at CPA
CPA(I, J, 10)	Y location of ZZ at CPA
DECAL (I, J)	Dummy event calendar, a copy of all events entered in the event calendar. The I <sup>th</sup> entry in DECAL contains:
DECAL(I, 1)	Event time
DECAL(I, 2)	Event number
DECAL(I, 3)	Number of screen ship in event
DECAL(I, 4)	Number of penetrating submarine in event
DECAL(I, 5)	Number of main body ship in event
DESKIL	An index of successful attacks by a penetrating submarine on a main body ship in a replication



<u>Name</u>	<u>Definition</u>
DSSV(I, J)	Dummy submarine vector containing initial information
DSSV(I, 1)	Number of I <sup>th</sup> penetrating submarine
DSSV(I, 3)	Speed of submarine
DSSV(I, 4)	Initial X location of submarine
DSSV(I, 5)	Initial Y location of submarine
DSTAT(I, J, K)	Detection range from ZZ in the I <sup>th</sup> replication for the R <sup>th</sup> submarine by the J <sup>th</sup> screen ship
DSV(I, J)	Dummy screen ship vector containing initial information
DSV(I, 1)	Number of I <sup>th</sup> screen ship
DSV(I, 2)	Initial screen ship course (in radians)
DSV(I, 3)	Screen ship speed
DSV(I, 4)	Initial screen ship X location
DSV(I, 5)	Initial screen ship Y location
DSV(I, 6)	Screen ship sonar type
DSV(I, 8)	Screen ship patrol area radius
DSV(I, 9)	Initial X location of center of assigned patrol area
DSV(I, 10)	Initial Y location of center of assigned patrol area
DTAR(I, J)	Dummy main body ship vector containing initial information
DTAR(I, 1)	Number of I <sup>th</sup> main body ship
DTAR(I, 2)	Initial main body ship course (in radians)
DTAR(I, 3)	Main body ship speed
DTAR(I, 4)	Initial X location of main body ship
DTAR(I, 5)	Initial Y location of main body ship



<u>Name</u>	<u>Definition</u>
EA1	Number of a screen ship
EA2	Number of a penetrating submarine
EA3	Number of a main body ship
ECAL(I, J)	I <sup>th</sup> entry in event calendar
ECAL(I, 1)	Event time
ECAL(I, 2)	Event number
ECAL(I, 3)	Number of screen ship in event
ECAL(I, 4)	Number of penetrating submarine in event
ECAL(I, 5)	Number of main body ship in event
EN	Event number
ET	Event time
KT	Index of total number of events entered in DECAL(I, J)
MAXEV	Maximum number of events allowed in ECAL(I, J)
MBKIL	Number of successful submarine penetrations in replication
MBKILL	Number of successful submarine penetrations in run
MSTAT(I)	Control vector for each run
MSTAT(1)	Number of screen ships in run
MSTAT(2)	Number of submarines in run
MSTAT(3)	Number of main body ships in run
MSTAT(4)	Number of replications in run
MSTAT(5)	Number of detections of submarine by screen ships to terminate run



<u>Name</u>	<u>Definition</u>
MSTAT(6)	Print screen ship detection range for each replication & average detection range for each screen ship during run
MSTAT(7)	Print out CPA & locations of each ship & submarine in replication
MSTAT(8)	Print out locations of screen ship, submarine, and ZZ at time of detection of a penetrating submarine by a screen ship
MSTAT(9)	Minimum submarine penetration speed
MSTAT(10)	Print out locations of screen ships, submarines, & ZZ at termination of each replication
MSTAT(11)	Print out event calendar for each replication
MSTAT(12)	Print out ship vectors for each replication
MSTAT(13)	Print out main body vectors for each replication
MSTAT(14)	Print out submarine vectors for each replication
MSTAT(15)	Submarine weapon release range (100's of yards)
MSTAT(16)	Print out locations of main body ship & submarine at weapon release for each replication
MTARK	Index of submarine attacks on main body ships
PI	3.14159
R	Index used in subroutine FIND to isolate sections of the subroutine after the first call on the subroutine



<u>Name</u>	<u>Definition</u>
SONAR(I, J)	The generated detection range of the J <sup>th</sup> screen ship for the I <sup>th</sup> replication in a run.
SONAV(I)	The average of generated detection ranges of the I <sup>th</sup> screen ship in a run
SSV(I, J)	Information vector of the I <sup>th</sup> submarine in a replication
SSV(I, 1)	Number of the I <sup>th</sup> submarine
SSV(I, 2)	Submarine course (in radians)
SSV(I, 3)	Submarine speed
SSV(I, 4)	Submarine X location
SSV(I, 5)	Submarine Y location
SSV(I, 6)	Time X-Y location fixed
SSV(I, 7)	Number of times detected by screen ships
SUBKIL	Number of times the penetrating submarines detected
SV(I, J)	Information vector of the I <sup>th</sup> screen ship in a replication
SV(I, 1)	Number of the I <sup>th</sup> screen ship
SV(I, 2)	Screen ship course (in radians)
SV(I, 3)	Screen ship speed
SV(I, 4)	Screen ship X location
SV(I, 5)	Screen ship Y location
SV(I, 6)	Screen ship sonar type
SV(I, 7)	Screen ship generated detection range
SV(I, 8)	Patrol area radius



<u>Name</u>	<u>Definition</u>
SV(I, 9)	X location of center of assigned patrol area
SV(I, 10)	Y location of center of assigned patrol area
SV(I, 11)	Time of next course change
SV(I, 12)	Number of submarines detected in replication
SV(I, 13)	Time X-Y location fixed
TAR(I, J)	Information vector for the I <sup>th</sup> main body ship
TAR(I, 1)	Number of the I <sup>th</sup> main body ship
TAR(I, 2)	Main body ship course (in radians)
TAR(I, 3)	Main body ship speed
TAR(I, 4)	Main body ship X location
TAR(I, 5)	Main body ship Y location
TEMP(I)	Used to aid in ordering event calendar as a temporary storage location for an event



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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Simulation						
War Game						
ASW Simulation Model						
Response Surface Methodology (RSM)						



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